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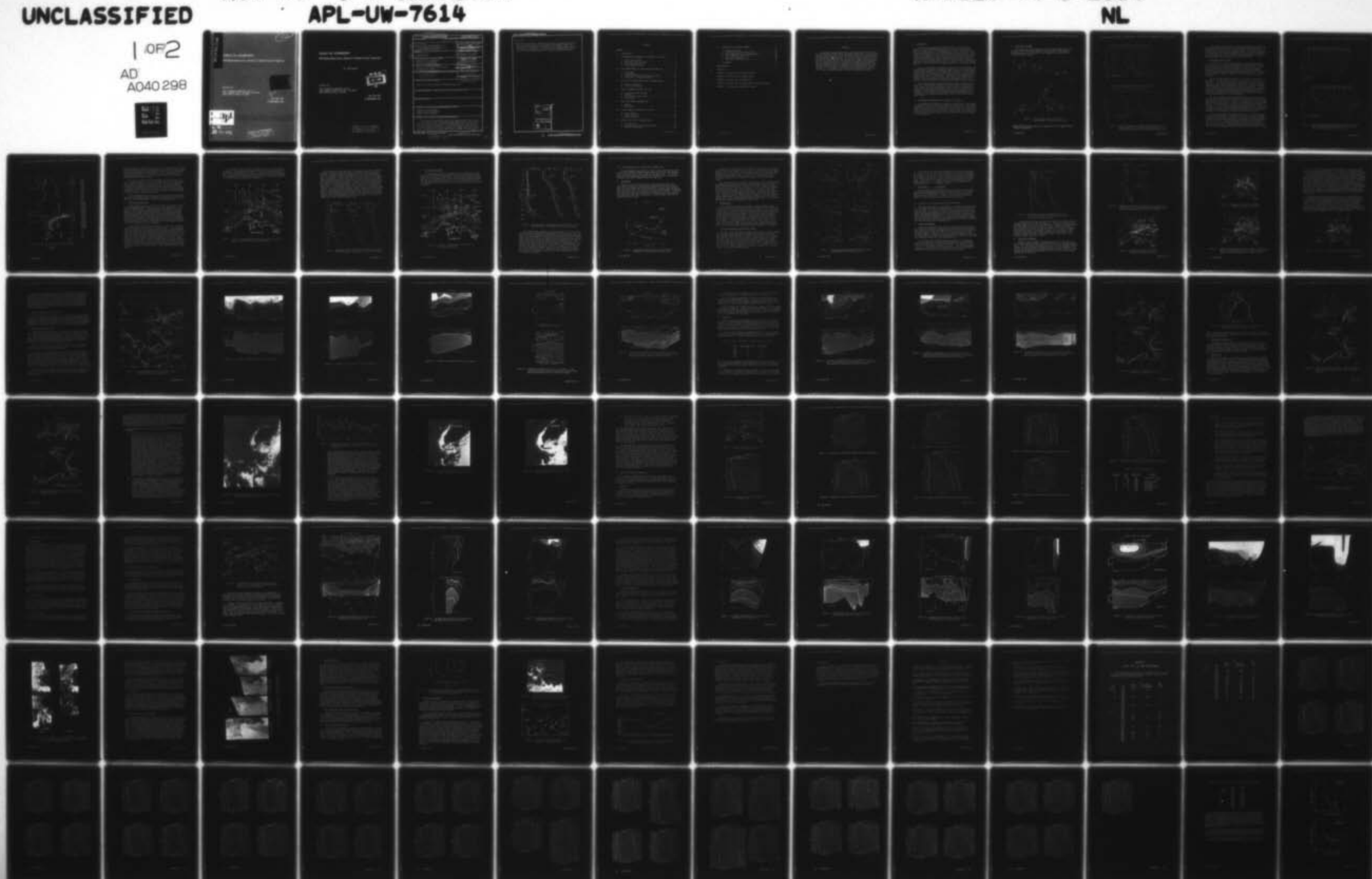

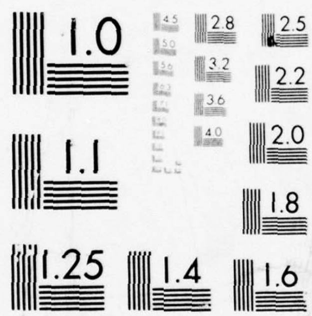

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CHUKCHI SEA OCEANOGRAPHY

1975 Measurements and a Review of Coastal Current Properties

PREPARED FOR:

ARCTIC SUBMARINE LABORATORY, CODE 90
NAVAL UNDERSEA CENTER, SAN DIEGO, CALIFORNIA
UNDER CONTRACT N00123-74-C-2064

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27 NOVEMBER 1976

APPLIED · PHYSICS · LABORATORY
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by G.R. Garrison

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Oceanographic measurements made in the spring through holes in the ice in an area off Barrow, where the Barrow Canyon forms a sloping trough from the shallow Chukchi sea into the deep Beaufort Sea, have revealed two interacting water movements: (1) a flow of highly saline water from the shallow Chukchi Sea into the Beaufort Sea through the Barrow Canyon, and (2) an uprising of Atlantic water from the depths of the Beaufort Sea
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CONTENTS

ABSTRACT

Oceanographic measurements made in the spring through holes in the ice in an area off Barrow, where the Barrow Canyon forms a sloping trough from the shallow Chukchi sea into the deep Beaufort Sea, have revealed two interacting water movements: (1) a flow of highly saline water from the shallow Chukchi Sea into the Beaufort Sea through the Barrow Canyon, and (2) an uprising of Atlantic water from the depths of the Beaufort Sea into the Barrow Canyon. Examination of earlier oceanographic measurements along the coast and recent satellite photographs reveals the Alaskan Coastal Current as a continuous, well-defined stream close to the coast. In the summer, the current flows northeasterly at 100-150 cm s^{-1}, while in other seasons it is weak and sometimes reversed.

I. INTRODUCTION

A series of oceanographic measurements off the arctic coast of Alaska has been conducted annually by this Laboratory since 1971 as part of an ongoing study of the Marginal Sea Ice Zone. These measurements have added greatly to our understanding of the annual cycle. Most of the shallow Chukchi Sea cools to the freezing point in winter, and is warmed by an intrusion of warm water through Bering Strait in the summer. Except when blocked by ice, this intrusion is concentrated along the coast to form the Alaskan Coastal Current, which can often be traced as a continuous flow from Bering Strait past Pt. Barrow. This current follows the Barrow Canyon, which forms a channel leading into the deeper Beaufort Sea.

Recent oceanographic measurements through the ice in the spring show evidence of water exchange through the Barrow Canyon even before the summer intrusion commences. This exchange takes two forms: (1) the higher density water in the Chukchi Sea flows down the sloping canyon into the Beaufort Sea, and (2) an uprising of Atlantic water in the Beaufort Sea brings warmer water into the canyon. Variations in the Alaskan Coastal Current, including reversals from the usual northeasterly flow, cause partial mixing of these waters, producing considerable thermal structure.

This report presents the 1975 measurements taken from an ice floe north of Pt. Barrow, from aircraft in a 150-km diameter area northeast of Pt. Barrow, and from an icebreaker along the coast. Additional material on the Alaskan Coastal Current has been taken from earlier measurements and from reports by other investigators to demonstrate the influence of the Alaskan Coastal Current and the Barrow Canyon on the interesting, ever changing oceanographic conditions found off Alaska's arctic coast.

II. OCEANOGRAPHIC MEASUREMENTS OFF BARROW IN THE SPRING

Oceanographic measurements were made from occupied ice floes during the periods 11-23 April 1974 and 23 March to 9 April 1975. Further measurements were made from a ski-equipped Cessna 180 aircraft using a lightweight CTD probe during 23-27 April 1975 and 14-19 May 1975. These temperature and salinity profiles revealed a great amount of variability in the area where the Barrow Canyon cuts the continental slope at the edge of the Beaufort Sea.

A. April 1974 Ice Camp*

The occupied ice floe remained above the Barrow Canyon 20 to 50 km northeast of Pt. Barrow (see Figure 1) for the entire 13-day period. CTD measurements were taken daily. The temperature and salinity profiles are shown in Figure 2.

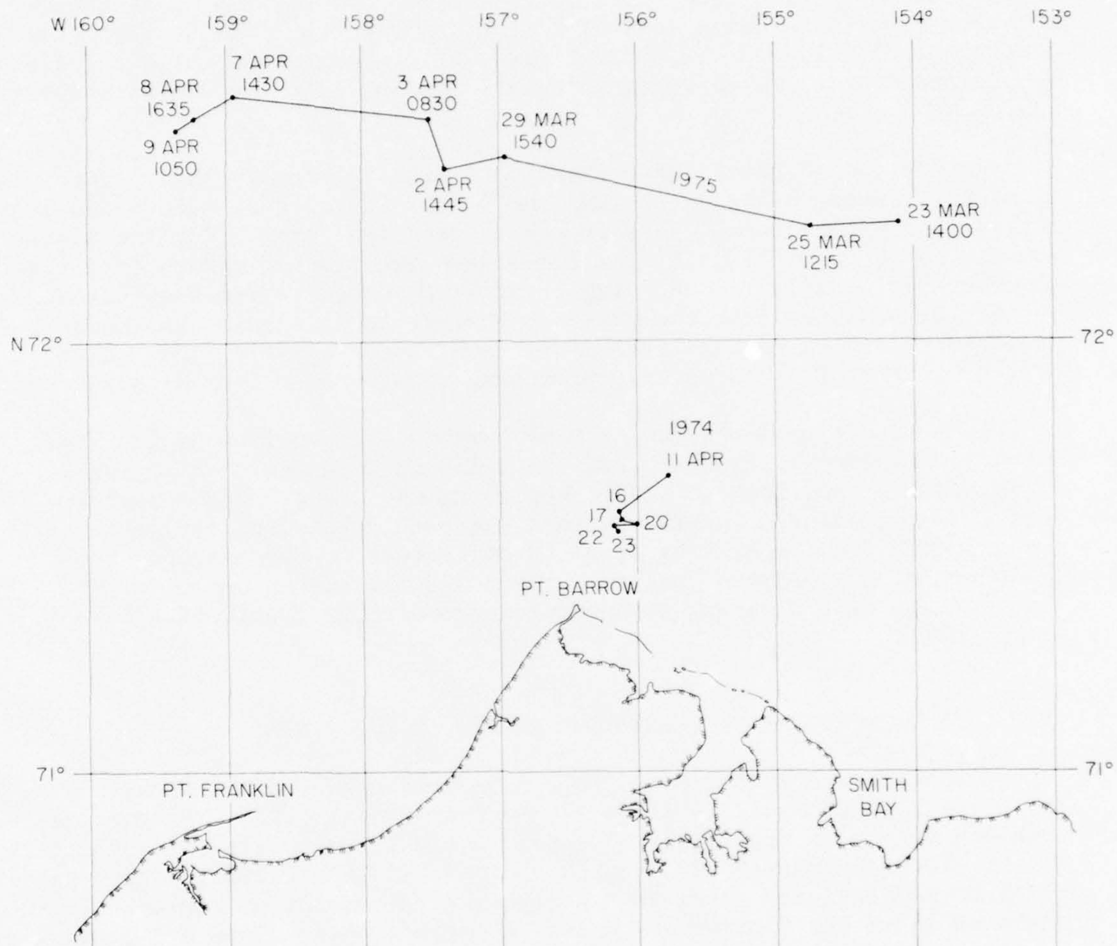

Figure 1. Ice floe drift tracks for the 1974 and 1975 camps. (Local times are given.)

*Reported in a previous report,[1] but repeated here for comparison with the 1975 measurements.

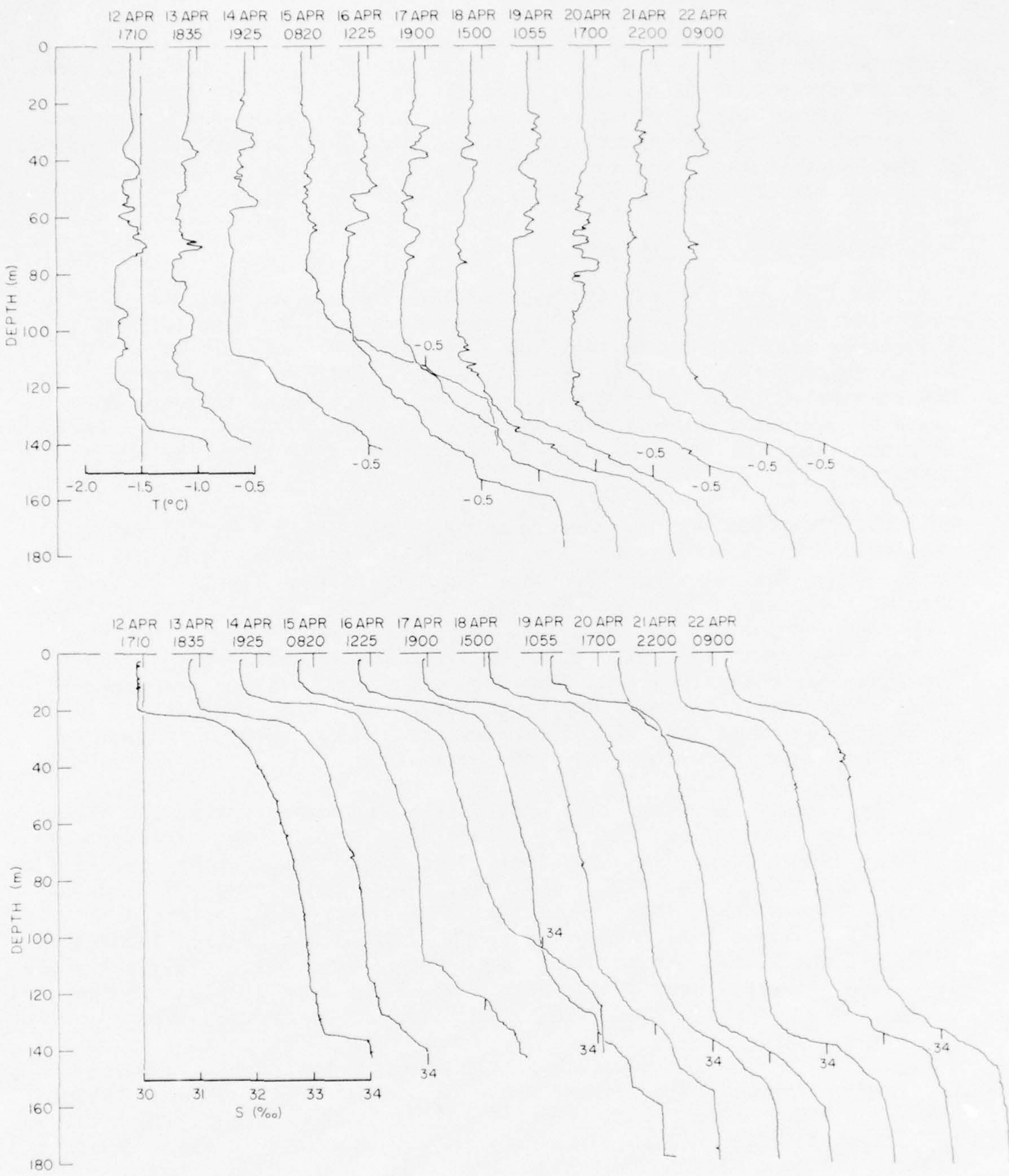

Figure 2. Daily temperature and salinity profiles taken at the ice camp in April 1974. See Figure 1 for locations. Some profiles are short because the depth was less than 180 m.

A low-salinity surface layer was present throughout the period. An intermediate region from 20 to 100 m deep contained considerable thermal microstructure resulting from a partial mixing of the near-freezing "Chukchi water" with the warmer "Beaufort water." Below 100 m appeared the transition to the higher-temperature, higher-salinity Atlantic water in the Beaufort Sea. The top of this layer was shallower in shallow water and deeper when the floe drifted into deeper water.

B. March-April 1975 Ice Camp

The 1975 ice camp was located farther from Barrow than the 1974 camp (see Figure 1). During its occupancy, it drifted about 200 km in a westerly direction, with the wind generally from the east at 10-20 kn. A representative series of profiles is presented in Figure 3. Unfortunately, the CTD cable was too short to reach the thermocline above the Atlantic water in the depths of the Beaufort Sea. On 4 April an extra length of cable was added, but shortly thereafter the depth decreased.

The first temperature profile shows a cold layer (-1.6°C) near the surface, a warmer layer (-1.5°C) at 35 m, and a cold region (-1.7°C) below 40 m. The later profiles show a warmer surface layer. We first thought the warm surface readings were erroneous, and that perhaps the temperature probe was too warm when the profile was started. However, if the temperature is corrected to the freezing temperature (-1.7°C), the salinity (determined from temperature and conductivity measurements) would be increased so much that an unstable condition would result. Therefore, although some of the temperatures in the upper 10 m seem to be too high, the error may, in fact, be small.

The salinity profiles show a halocline that drops during the first few days and another one near the bottom that rises as the water shoals. These changes are best seen in Figure 4, a depth-time plot of several isohalines (read right to left). Note that the isohalines of 32‰ and 33‰ rise as the water shallows. A region of very constant properties (S = 33.1‰, T = -1.75°C) is evident along the edge of the shelf. Water this cold must have come down the slope from the Chukchi Sea. The water above it, which is warmer, may be the result of an uprising of water in the Beaufort Sea (this uprising is discussed further in Section IV).

Current measurements were made almost daily by lowering a Marsh-McBirney electromagnetic current probe to each 10 m of depth and taking a reading after the meter stabilized. The recorded currents are with respect to the ice floe which was moving westerly at an average speed of 0.27 kn (14 cm s^{-1}). The polar diagrams of current which appear on pages A15 through A19 of Appendix A have the ice floe as the origin. A vector from the origin to the plotted point for each depth represents the direction and magnitude of the current relative to the floe. A cross

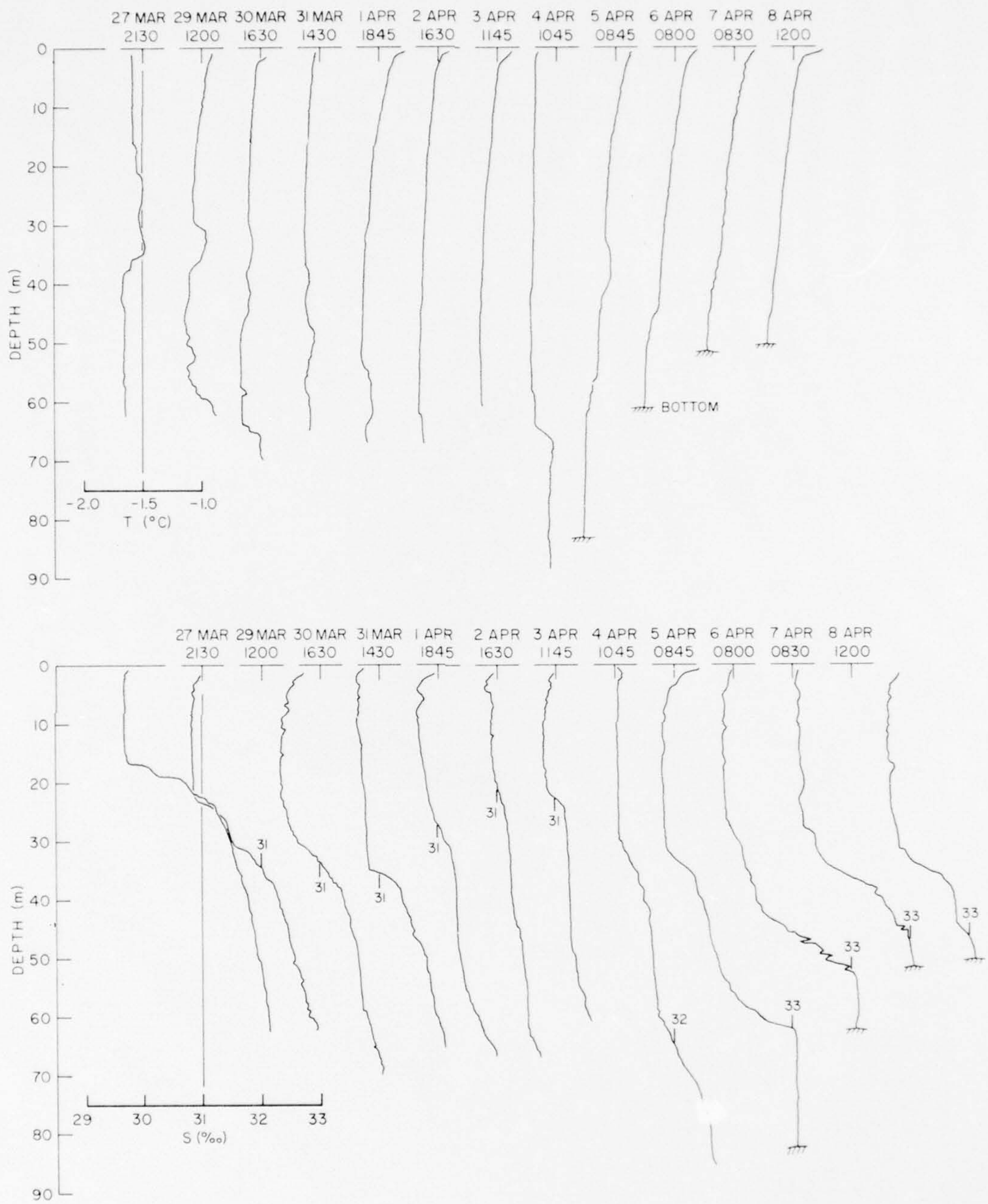

Figure 3. Daily temperature and salinity profiles taken at the ice camp in March-April 1975. See Figure 1 for locations. The last four profiles extend to the bottom.

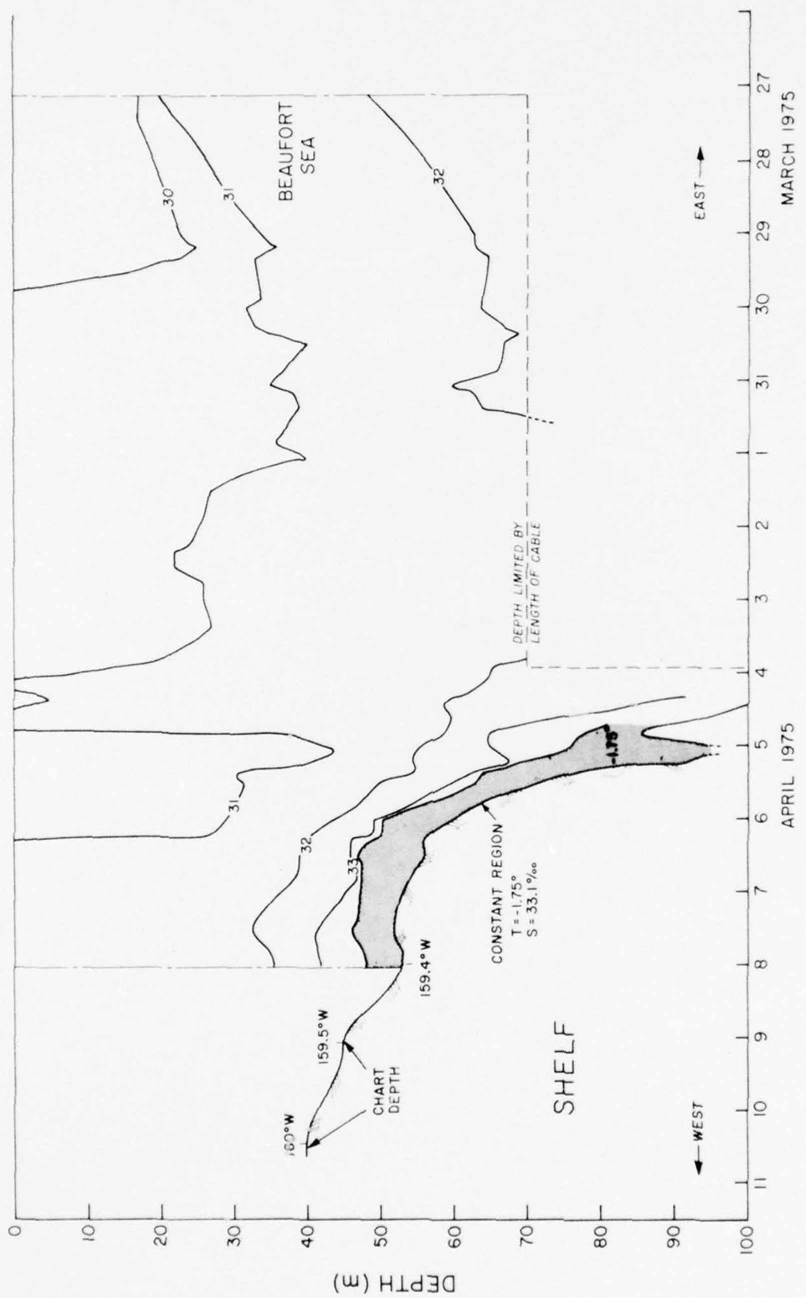

Figure 4. Isohalines for a series of profiles taken as the ice floe drifted westward across the edge of the continental shelf. See Figure 1 for the locations.

has been plotted to represent the average floe movement during 3-7 April. On 8 April the floe was nearly stationary, and no cross has been plotted. For some measurements the reading near the bottom may be a better estimate of floe movement; these are plotted as an X. Vectors from the assumed stationary point (X or cross) to the plotted points for each depth represent the true current.

On 2 April a current measurement showed a very low current (1.5 cm s^{-1}) from the surface to 70 m. The graphs for the next several days show variable currents up to 10 or 15 cm s^{-1}. The surface layer was generally moving westerly and the lower layers moved more southerly. As the floe approached the shelf there is an indication that the flow was easterly (see graphs for 5 and 6 April) for the bottom layer shown in Figures 3 and 4. On 8 April, the floe was above the shelf and both drift and measured currents were small.

All the temperature and salinity profiles measured from the March-April 1975 ice camp are shown in Appendix A, along with the sound speed profiles, weather observations, and the current measurements.

C. 23-27 April 1975 Survey

Oceanographic surveys in the Arctic in the spring require a rapid mode of transportation over the ice. Since this requirement is best met with light aircraft, a lightweight STD or CTD profiler is a necessity. The 1975 spring surveys were made possible by our recent development of a highly portable CTD profiler. Its lightness results from (1) the absence of slip rings in the winch (the recording equipment is mounted in the hub and rotates with the drum), (2) a conductivity probe (designed by Pederson[2]) that is 20 cm long and weighs less than 1 kg, and (3) the use of a hand-operated winch, which is feasible because of the light probe. A description of the development and testing of this profiler is given in Appendix E.

For the April survey, the CTD winch was installed in a Cessna 180 aircraft from which the rear seats had been removed. After the plane landed on the ice and a 23-cm hole was drilled with a gasoline-powered auger, the probe and cable were passed out through the small door at the rear of the passenger compartment and lowered through the hole. Each operation--the search for a suitable landing space, hole drilling, the profiling itself, equipment storage and takeoff--took 1 hour on the average. A second plane was used for safety and to carry an assistant who helped make the cast. After the takeoff from the station, one plane circled a few thousand feet over the station while a radar fix was obtained from Barrow. The radar fix was a time- and fuel-consuming operation and was therefore omitted when the dead-reckoning position seemed adequate.

The locations of the stations (estimated accuracy, 5 km) are shown in Figure 5. The contours were drawn from coast and geodetic charts and considerable interpolation was required. These inaccuracies should be kept in mind when examining the profiles in relation to the Barrow Canyon. The temperature and salinity profiles for all the measurements during the 23-27 April survey are presented in Appendix B.

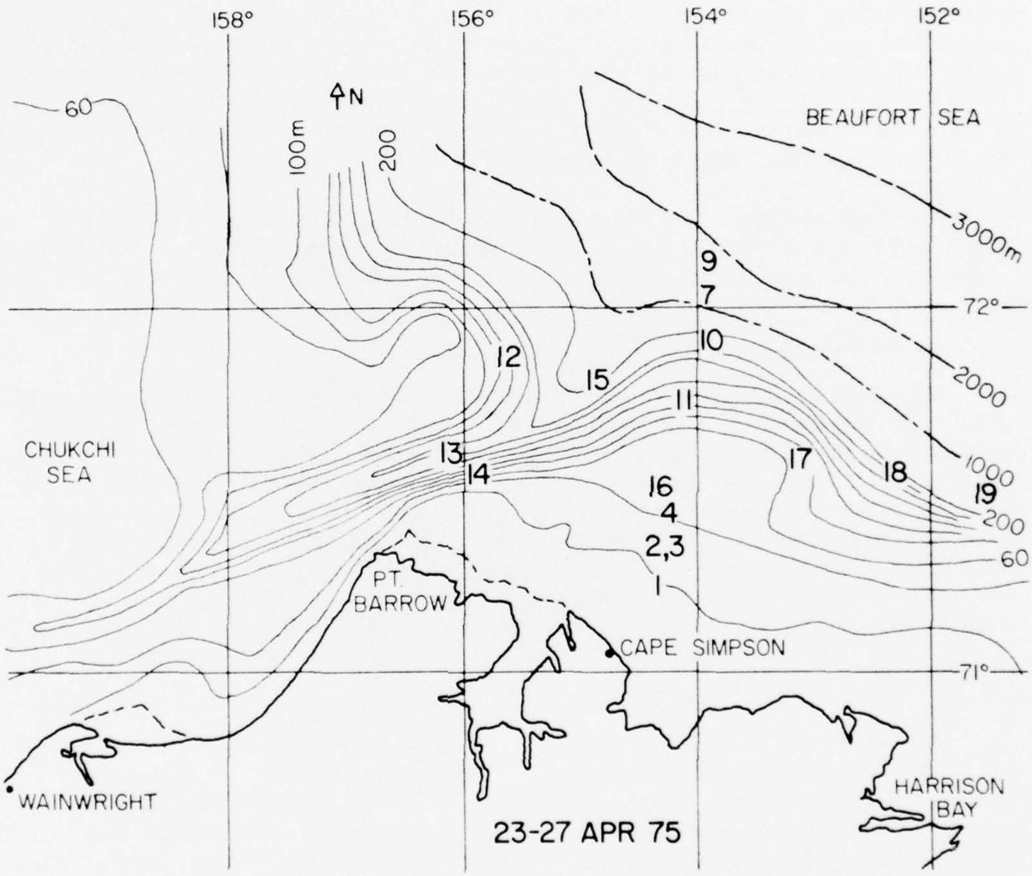

Figure 5. Location of oceanographic stations for the 23-27 April 1975 survey. Stations 5, 6, and 8 were cancelled.

We have selected four stations as indicative of the area. The temperature, salinity, and density profiles for these stations appear in Figure 6. Station 19 shows the conditions farthest into the Beaufort Sea. The thermocline above the Atlantic water can be seen at the lower end of the profile. A broad layer from 30 to 90 m contains the slightly warmer Beaufort water that is generally attributed to the previous summer's intrusion from the Bering Sea. Station 15 shows the conditions in the middle of the Barrow Canyon near its outer end. The Chukchi winter water fills the lower region down to 180 m, where there is an abrupt thermocline. At intermediate depths, considerable -1.5°C Beaufort water remains. Station 14, well up into the canyon, shows mostly Chukchi water to 120 m; the thermocline and halocline at 140 m show that the Atlantic water is much shallower than would be expected. Station 16 shows conditions on the shallow shelf east of Barrow. Both the temperature and the salinity at the bottom approximate the values observed at much greater depths for stations farther from the coast.

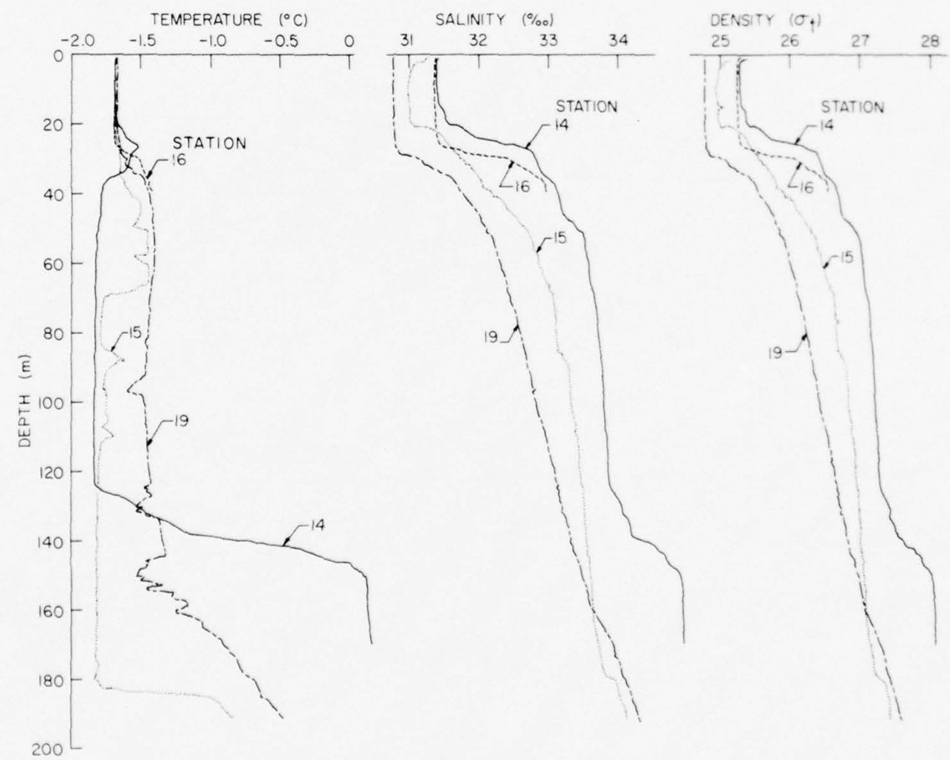

Figure 6. Temperature and salinity profiles representative of the April 1975 survey. See Figure 5 for station locations.

D. 14-19 May 1975 Survey

The second spring survey was conducted in the same manner as the first, except that more care was taken to lower the probe to the full length of the cable or to the bottom. The station locations are shown in Figure 7; the letters A, B, or C before the station numbers indicate that the measurements were taken on 14, 15, or 19 May, respectively. The temperature and salinity profiles for the measurements are presented in Appendix C.

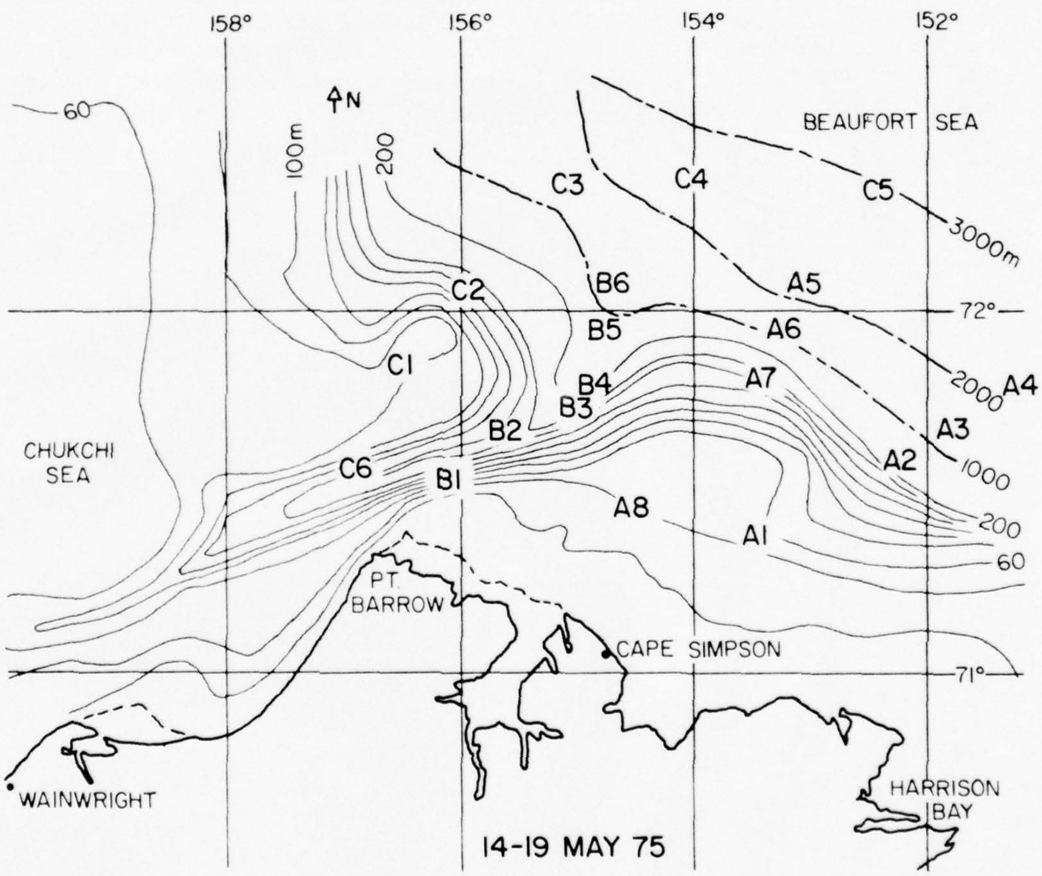

Figure 7. Location of oceanographic stations for the 14-19 May 1975 survey.

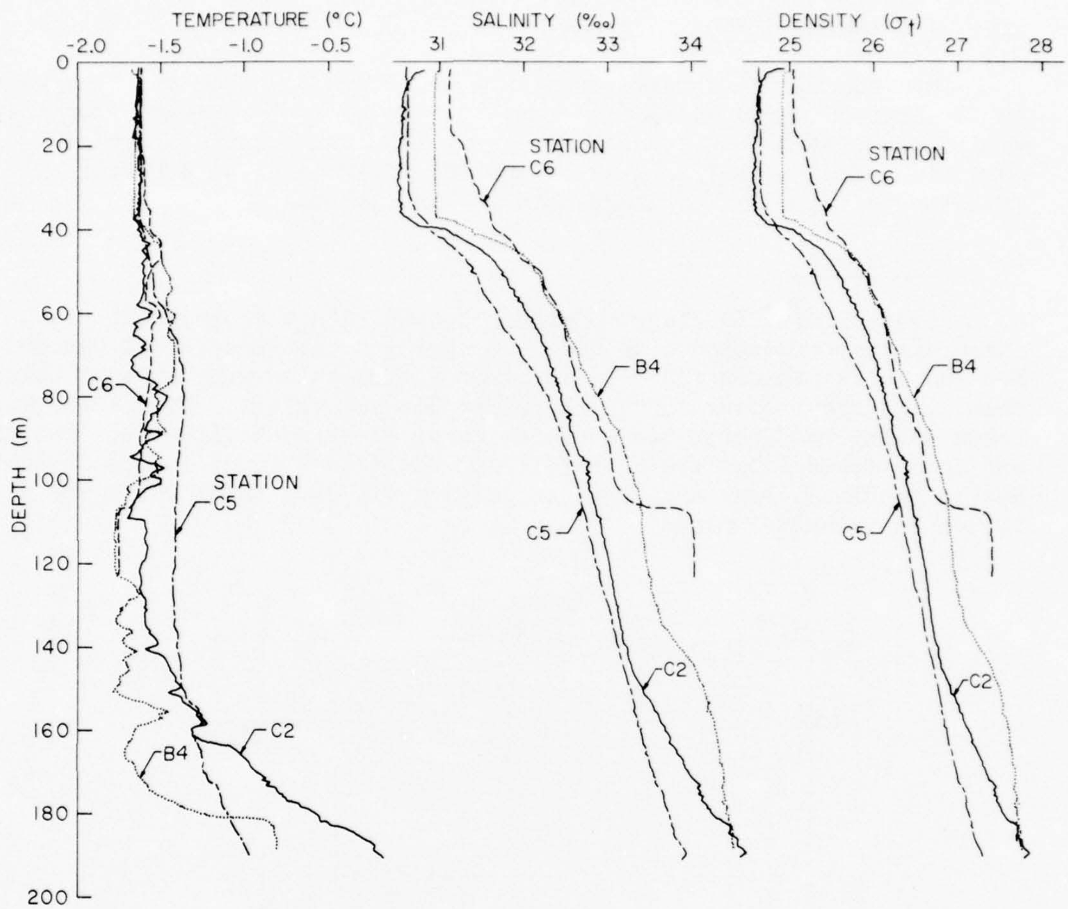

Figure 8. Temperature and salinity profiles representative of the May 1975 survey. See Figure 7 for station locations.

Four representative stations are shown in Figure 8. Station C6 is in the shallower (southwestern) portion of the Barrow Canyon. Here, the temperature is intermediate between Chukchi water and the warmer Beaufort water. Near the bottom is a 14-m thick layer of water with very uniform temperature and salinity (this feature will be discussed in the next section). Station B4, toward the lower end of the canyon, shows a layer at intermediate depth (40-100 m) that is similar to Beaufort water and a layer at lower depth (100-180 m) that is similar to Chukchi water, with Atlantic water lying below 180 m. Station C2, which is at the edge of the Chukchi shelf and north of the canyon, shows considerable partial mixing at intermediate depths. Station C5 was the farthest station to the northeast; it appears to contain very little Chukchi water and to be free of microstructure.

III. THE BARROW CANYON AS A DRAIN FOR THE CHUKCHI SEA

The oceanographic measurements in April and May show that the waters in the Barrow Canyon and beyond contain both Chukchi water and Beaufort water, along with some Atlantic water at the lower depths. A closer examination using temperature-salinity (TS) diagrams gives a better understanding of the water exchange between the two seas.

A. TS Diagrams

Figure 9 is a TS diagram, with the temperature expanded to fit these special conditions, showing the spring conditions in the Chukchi Sea and in the Beaufort Sea as far from Barrow as we were able to obtain them. The other curve for the Beaufort Sea was obtained from measurements taken during the Arctic Ice Dynamics Joint Experiment (AIDJEX). The third and lower curve shows the near-freezing conditions found in the Chukchi Sea in previous years and is essentially a freezing point curve for the indicated salinity values.

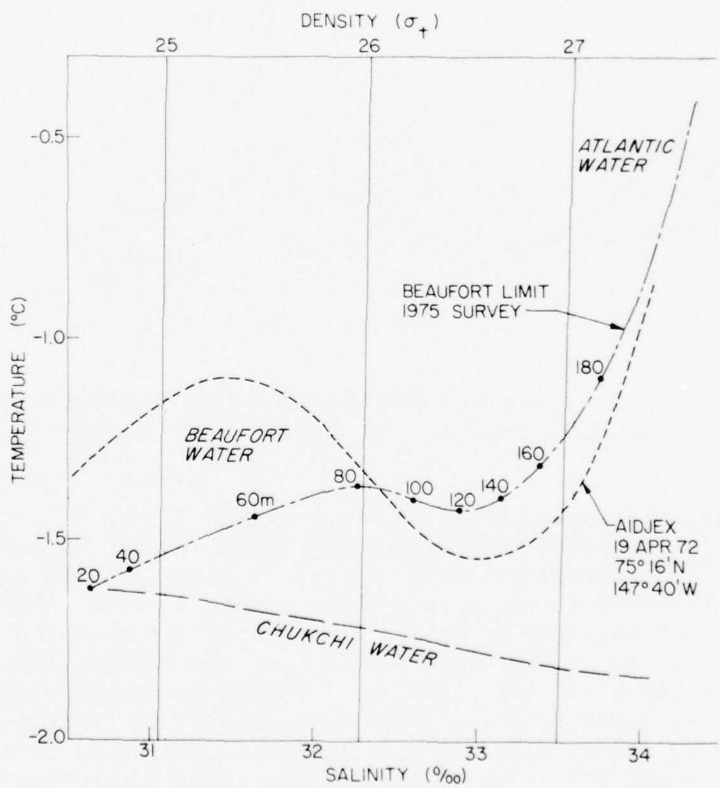

Figure 9. Temperature-salinity diagram showing limiting conditions in the Beaufort and Chukchi Seas.

With these two water masses as reference, we now look at six of the profiles taken in April and May (see Figure 10). Station C6, the station farthest west in the canyon, shows partially mixed water with about equal proportions of each water mass. Similarly, Station C2, at the edge of the slope farther north, shows equal amounts of interacting waters at intermediate depths, with a merging into Atlantic water at the lower depths.

For Stations 14, B2, B3, and B5, which progress northeastward through the canyon, the remaining TS diagrams show progressively less Chukchi water and more Beaufort water. Each water mass often appears at greatly different depths (as also shown in Figures 6 and 8). Station B2 shows a thin layer of warmer water at 110 m which must be Beaufort water that has been cooled by contact with Chukchi water. Station B3 shows similar layers, but the lower one appears to be Beaufort water that has risen 70 m. Station B5, farther down the canyon, appears to contain unchanged Beaufort water above 80 m, with intrusions of Chukchi water near 100 m and at 130 to 180 m, showing that the Chukchi water sinks as it progresses northeastward through and beyond the canyon mouth.

B. Bottom Water

The TS diagram for Station 14 (Figure 10, third diagram) shows a very cold region (-1.8°C) at 40-120 m with a salinity of 33 to 34‰. Our records for 1971 and 1972 show that such high salinities are often found in the Chukchi Sea and that they are associated with a region of constant temperature and salinity, as though they were formed when the entire column cooled to the freezing point. They are most likely produced in the more shallow areas of the Chukchi Sea during the freezing process at the surface. Such high-density water would tend to move to the lower depths. In order to appear in the middle of the canyon, it must have flowed down the canyon; a 15-m layer of water with constant properties and salinity of 34‰ farther up the canyon supports this assumption (see the lower portion of the profiles for Station C6 in Figure 8).

C. Estimated Transport Through Barrow Canyon

The more saline, and hence more dense, water from the shallow Chukchi Sea apparently flows down into the Beaufort Sea mainly by the easiest path, through the Barrow Canyon, although smaller amounts also appear to flow down the slopes north of the canyon. Assuming this process starts soon after most of the ice has formed, possibly in February, it would have been under way for 3 months at the time of the May observations. To fill the observed volume (a 150-km x 90-km area to a depth of 50 m) in 3 months would require a transport of 0.09 Sv.* The intrusion of cold, dense water may extend farther; our easternmost station, A4, still contained a large amount of Chukchi water.

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*1 Sv = 10^6 m^3 s^{-1}

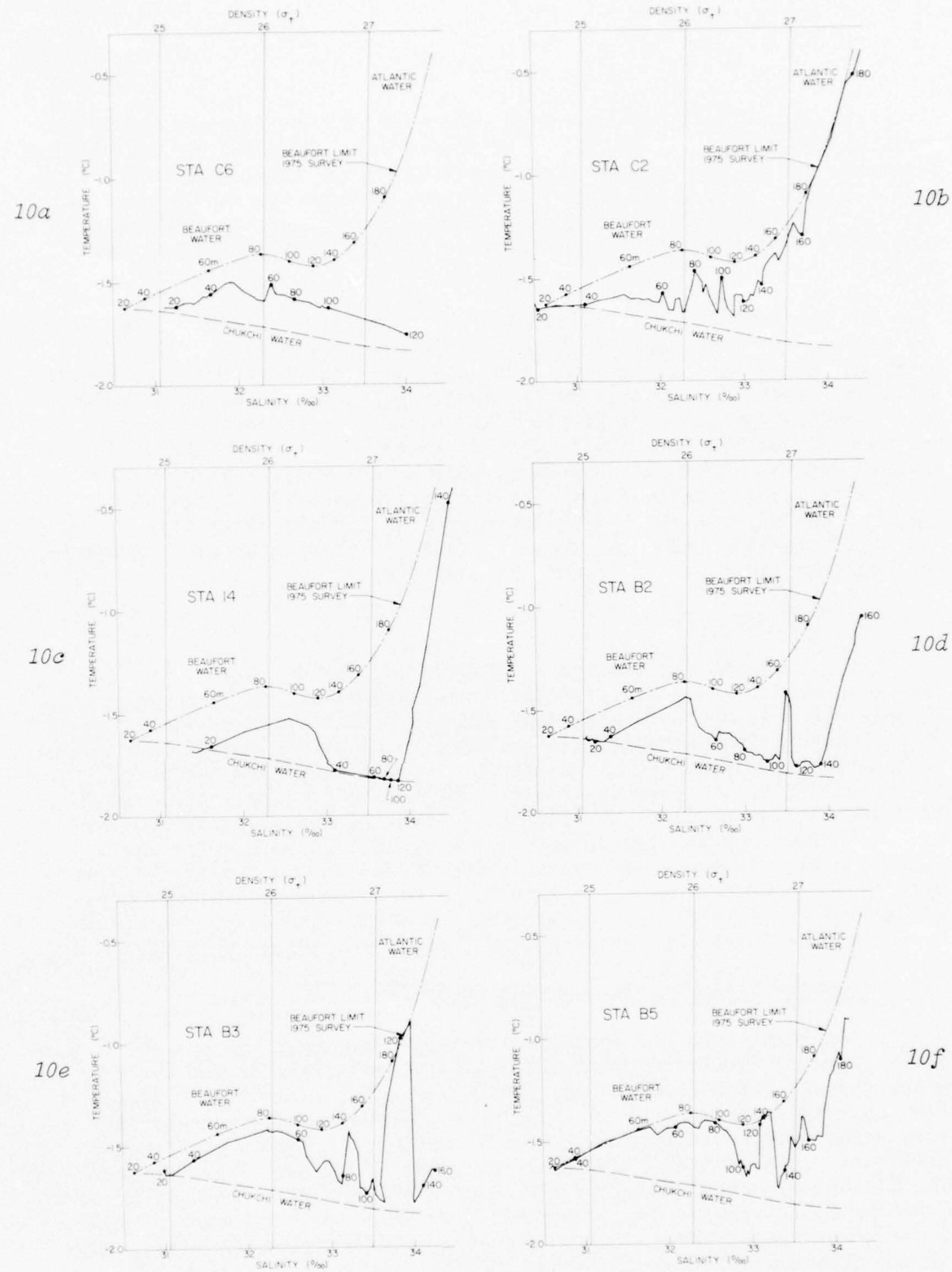


Figure 10. Temperature-salinity diagrams for several of the profiles taken in April and May 1975.

If we examine the current measurements in the canyon by Mountain[3] for 20 April to 15 May 1973, take as averages 5 cm s^{-1} for 15 February to 1 May and 20 cm s^{-1} for 1 May to 15 May, and assume the flow averages 20 km wide and 50 m deep, we obtain, for the average transport during the 3 months, 0.08 Sv--which agrees well with the transport calculated above. This calculation indicates that the flow through the canyon could supply the volume of Chukchi water that has accumulated in the Beaufort Sea just off the end of the canyon.

D. Conclusion: A Chukchi Sea Drain

Having identified dense Chukchi water off the mouth of the Barrow Canyon and having demonstrated that the quantity of water is in agreement with the flow through the canyon, we feel justified in stating that the Barrow Canyon acts as a drain, as suggested by Paquette and Bourke,[4] for the Chukchi Sea during the winter and spring.

IV. THE RISE OF ATLANTIC WATER INTO THE BARROW CANYON

The spring measurements of temperature and salinity off Barrow show that the isopycnals rise as the water shoals. The reason for this rise is not evident. It could be caused by a long period of easterly winds along the coast that produces an offshore Ekman transport in the surface layers and subsequent upwelling, but available weather records do not show a sufficiently persistent wind. Also, the ice cover would greatly reduce the wind-sea interaction. The isopycnal slope observed is apparently not the usual coastal upwelling as described by Hufford;[5] therefore the term "uprising" seems more appropriate.

A. Slope of Isopycnals

The April measurements show a rise in salinity as the water shoals. The profiles for Stations 16 through 19, plotted together in Figure 11, show water with a salinity of 33‰ rising from 114 m to 40 m as the bottom depth decreases from 138 m to 40 m. This uprising seen in the salinity profiles is consistent with observations by Mountain[3] that the 0°C temperatures he found in the Barrow Canyon must represent an uprising 150 m above the normal level in the Beaufort Sea.

We had previously observed temperature anomalies in the Barrow Canyon on 29 April 1972 (see Figure 56 on page 66). The profile for the first station shows a layer at 30 m with -1.4°C water in contrast to -1.7 to -1.8°C water at the other stations. The 1975 measurements show that a possible source of such warm water at this time of year is the Beaufort Sea at about 80 m, rising up into the canyon.

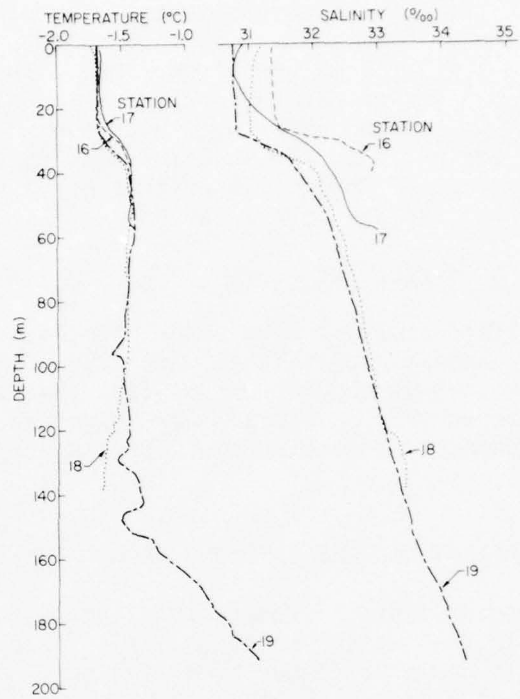


Figure 11. Temperature and salinity profiles for a line of stations from the shelf east into deep water for the 23-27 April 1975 survey.

A comparison of the May temperature and salinity profiles at varying distances from Barrow is given in Figure 12. The rise in salinity (and therefore density) as the coast is approached is apparent, with salinities of 33 and 34‰ rising 100 m in 100 km. Figure 13 shows the depths at which water with a salinity of 34‰ was found at all stations. Contour lines have been added at 20-m depth intervals for a salinity of 34‰ to illustrate the rise in the salinity levels as the water shoals. The average isopycnal slope for a salinity of 34‰ is about 0.0011. For a salinity of 33‰, the slope is 0.0014.

B. Direction of Uprising

Figures 14 and 15 compare the depth contours for a salinity of 33 for the April and May surveys, respectively, which were taken three weeks apart. The arrows drawn on Figure 15 indicate the water movement required to make this change during the 3-week interval. Such a comparison is imprecise, but does indicate a movement more westerly than southerly. This agrees with the general circulation of Atlantic water given by Coachman and Barnes[6] for this area.

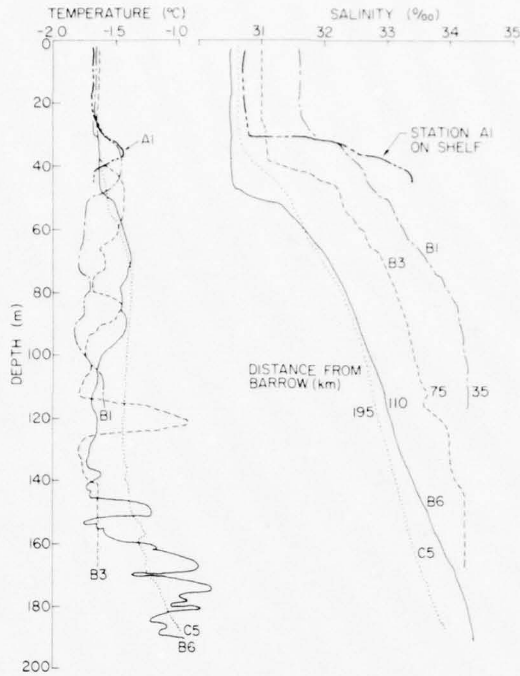


Figure 12. Temperature and salinity profiles for a station on the shelf and a line of stations extending northeasterly from the canyon mouth from the 14-19 May 1975 survey.

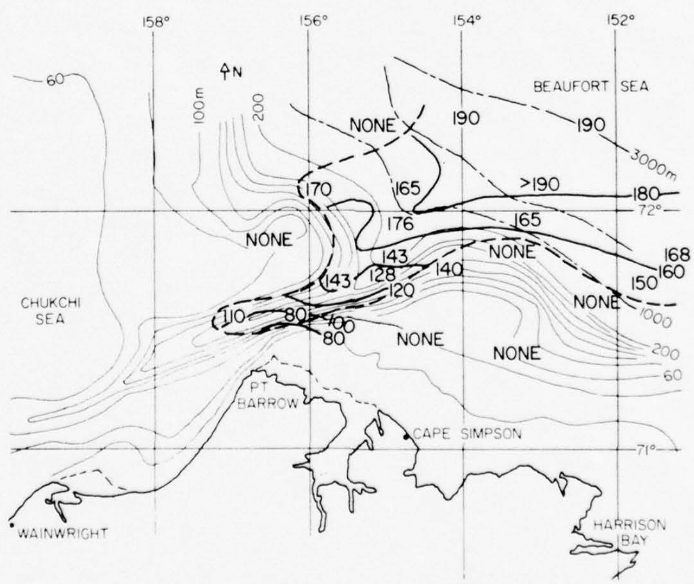


Figure 13. Depths and contours for salinity of 34‰ for the May 1975 survey.

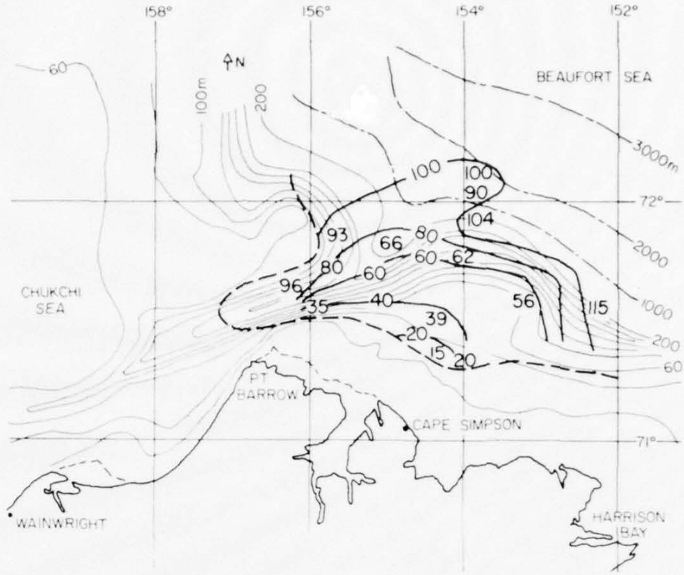


Figure 14. Depths and contours for salinity of 33‰ for the April 1975 survey.

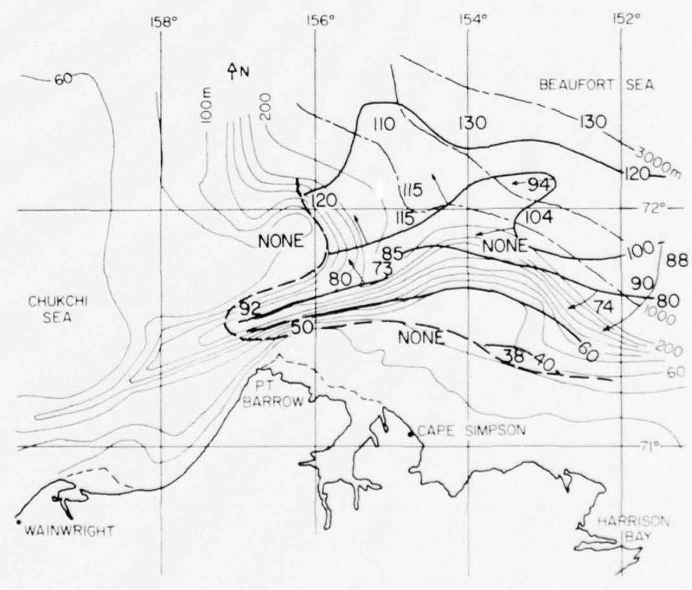


Figure 15. Depths and contours for salinity of 33‰ for the May 1975 survey. Arrows indicate direction of water movement to change from the April contours to the May contours.

There are other indications that the movement of the higher density water is more westerly than southerly. For example, a maximum salinity of 33.4‰ is found at the bottom of Station A1. (For locations, see Figure 7. The profiles are shown in Appendix C.) Station A2 to the northeast has a bottom salinity of 33.5 ‰ while Station A7 to the north has a bottom salinity of only 32.8‰, indicating the water movement must have been from A2 to A1 (southwesterly) rather than from A7 to A1 (southerly). In Figure 10 another example can be seen in the warm layer occurring at 110 m at Station B2 and at 120 m at Station B3, which is farther down the canyon. This layer is much thicker at Station B3. If this water were moving down the canyon, the layer at B2 would probably be the larger. A better explanation is that the layer is formed by water flowing westward across the Beaufort shelf, which lies east of the canyon and has the proper depth to act as a sill. Warm water of the proper salinity was found farther east at Station A6.

The uprising can also be observed in the rise in the isothermals associated with the upslope into the Barrow Canyon. Figure 16 is a plot of the depths at which temperatures of -1°C were observed during both surveys. Water of this temperature rises from 188 m in the Beaufort Sea to 120 m in the canyon, where it would very likely mix with the colder (-1.7°C) Chukchi water. When the coastal current flows southwesterly, this warmer water could be carried some distance along the canyon (the warmer layer observed southwest of Barrow and shown in Figure 56, page 66, may be an example of such an occurrence in 1972).

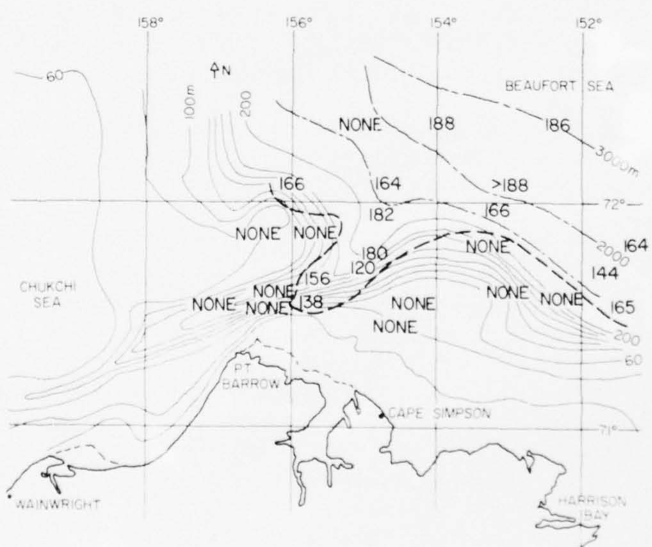


Figure 16. Depths of -1°C water for the April and May 1975 surveys.

The uprising we observed in and near the Barrow Canyon is similar in magnitude to that observed by Mountain[7] in August 1972 farther east along the coast. However, in our case, the direction of high-density water movement appears to be more along the coast than perpendicular to it, with the high-density water rising into the canyon. Also, considering that the ice cover would reduce wind stress, it appears that the explanation given by Mountain--that the upwelling he observed was caused by wind stress along the coast--could not apply to the spring uprising reported here.

V. NOME TO WAINWRIGHT CRUISE, JULY 1975

The USCGC GLACIER cruised from Nome to Wainwright during the period 30 July to 11 August. Oceanographic measurements from GLACIER were made by personnel from both the Laboratory and the Naval Postgraduate School at Monterey, California. CTD profiles were obtained using our lightweight profiler. All of the data taken on the cruise were to be analyzed independently by each group in different, but perhaps overlapping, studies.

A. Profiles and Cross Sections

The CTD data have been converted to temperature, salinity and density profiles which are presented for each station in Appendix D. Figure 17 shows the location of the stations. The approximate edge of the ice, a very difficult boundary to define, is shown as a dotted line. The heavy lines indicate series of stations for which a sectional view has been plotted. The letters correspond to the sectional views with isotherms and isohalines presented in Figures 18 to 25.

Figure 18, for Line A, shows warm water in the strait and a warm surface layer (9°C maximum) extending to Pt. Hope. The intrusion of Bering Sea water has a salinity of about 31‰.

In Figure 19, for Line B off Pt Hope, the warmest surface water is about 15 miles off shore. Figure 20, for Line C farther up the coast, shows that the warm intrusion has moved northward beyond Cape Lisburne with no tendency to follow the coast. Line D, a short section across the ice edge further north (Figure 21), shows slightly colder water beneath the ice, and a low-salinity surface layer (23‰ minimum). A layer whose temperature and salinity are constant with depth lies along the bottom and is shown by a dashed line. The properties of this layer, however, vary slightly with location (see discussion in Part D of this section).

Figure 22 shows isotherms and isohalines for a long section, Line E, normal to the coast off Icy Cape. The temperature of the intrusion is only 2°C here, and has split into a branch to the north and a branch along the coast.

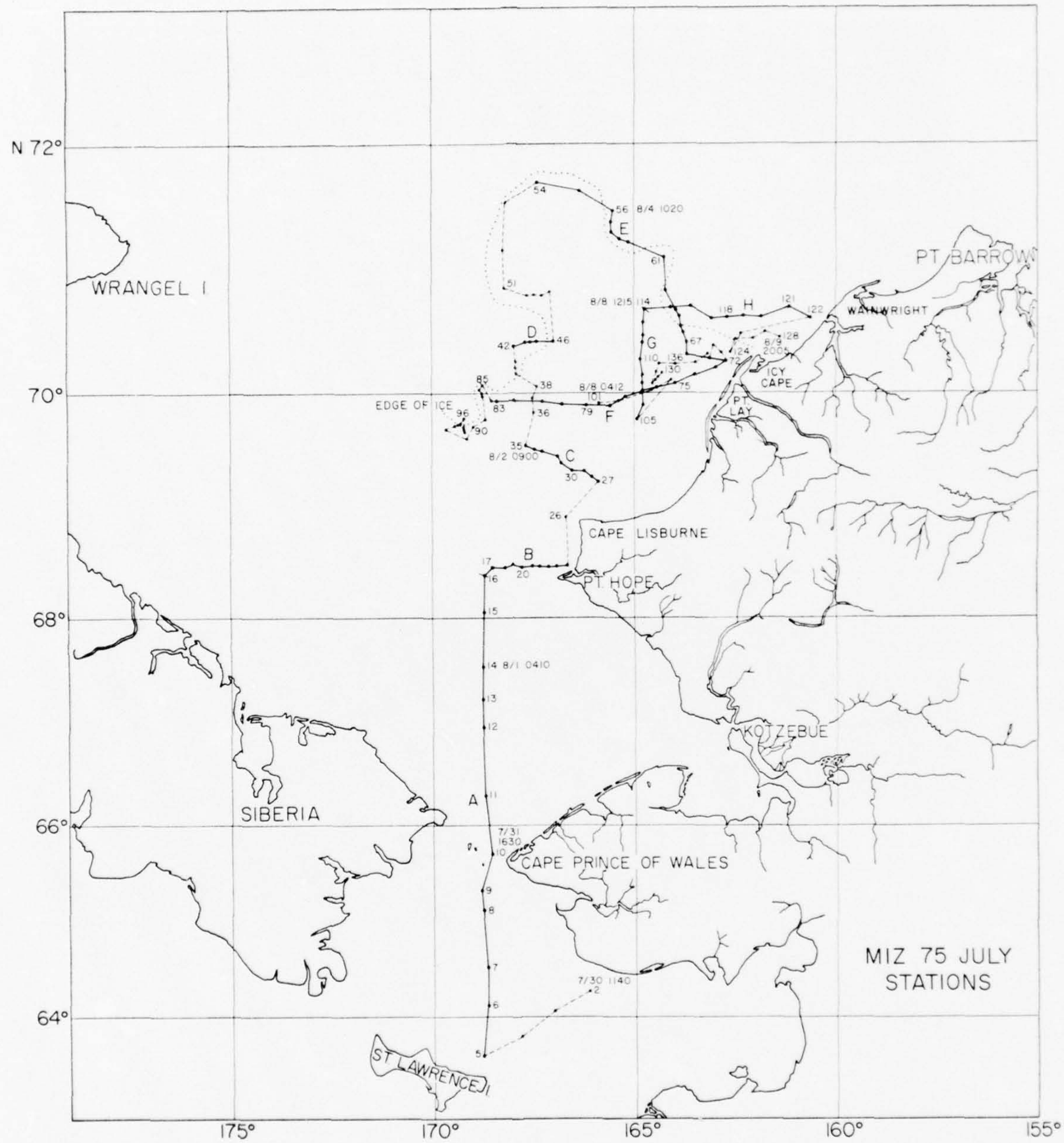


Figure 17. Cruise track for the Nome to Wainwright cruise on the USCGC GLACIER in July-August 1975.

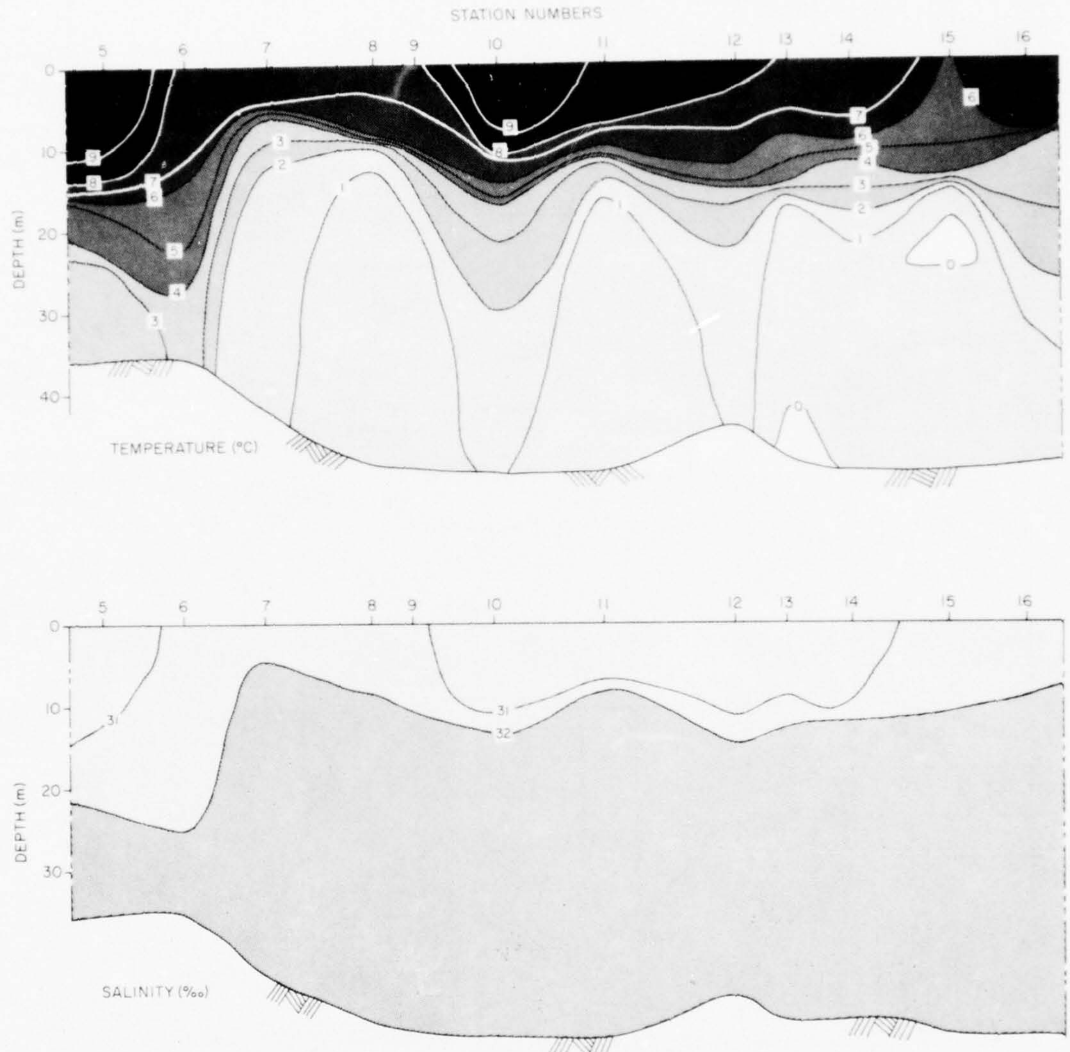


Figure 18. Isotherms and isohalines for Line A in Figure 17.

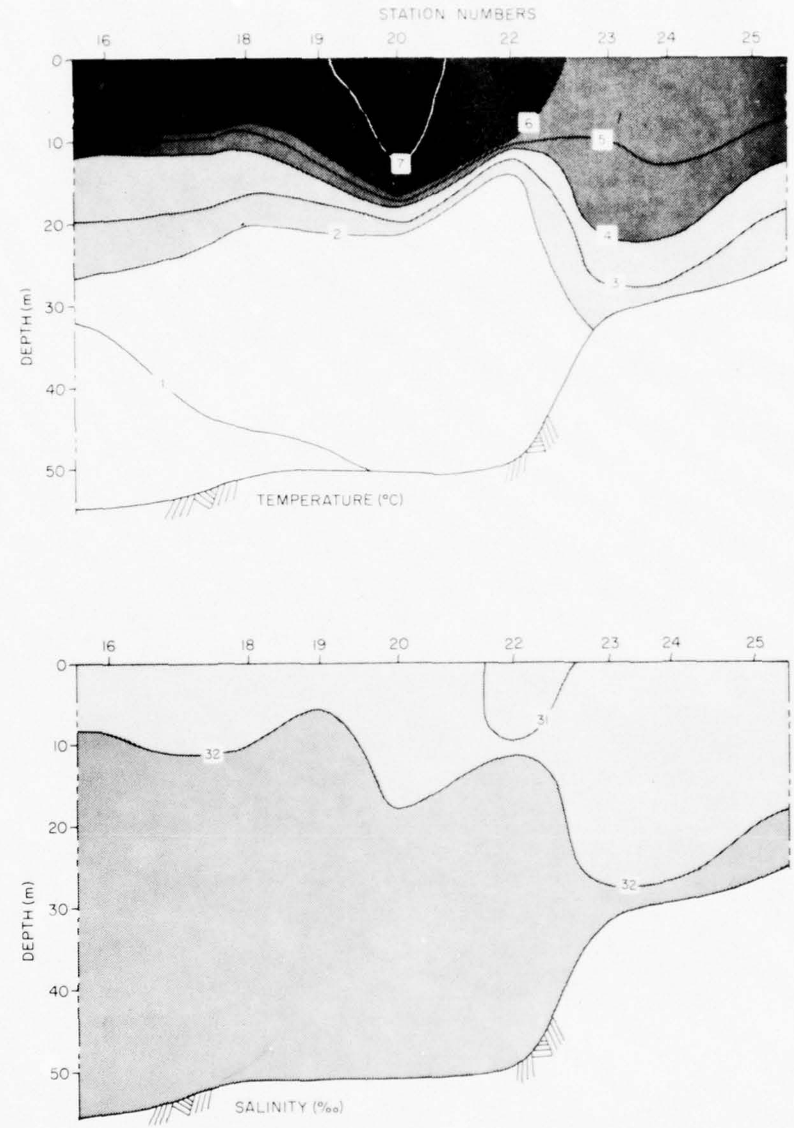


Figure 19. Isotherms and isohalines for Line B in Figure 17.

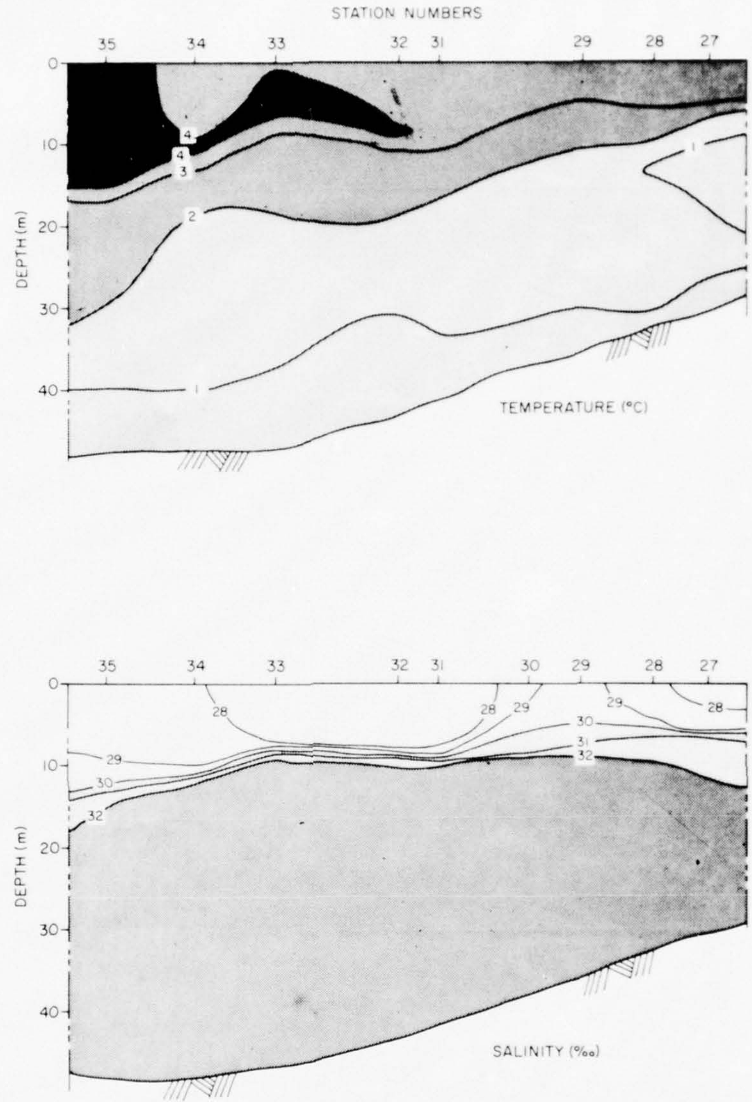


Figure 20. Isotherms and isohalines for Line C in Figure 17.

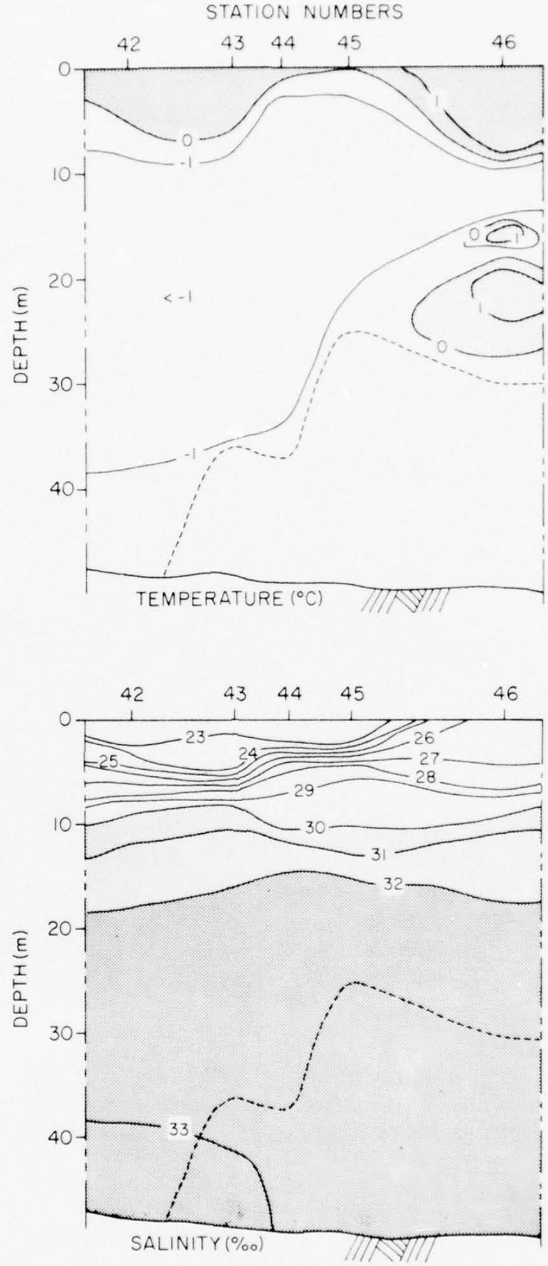
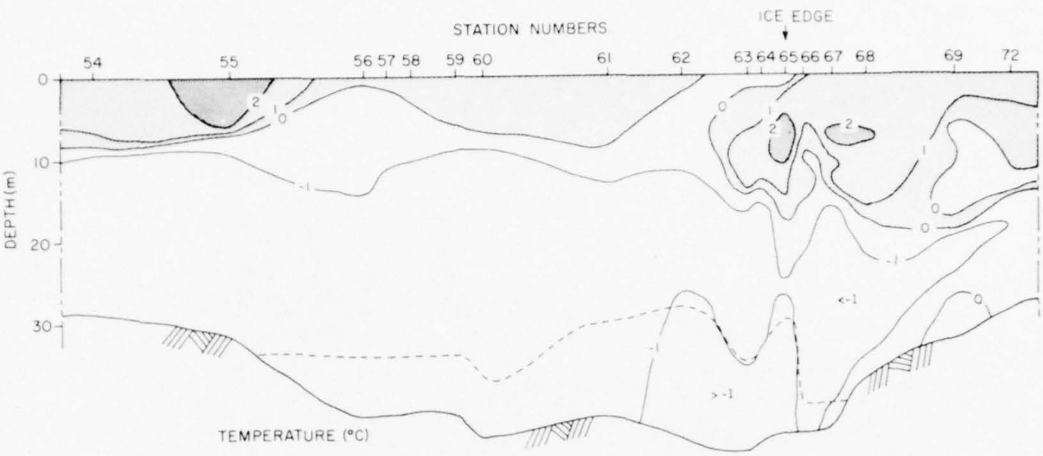


Figure 21. Isotherms and isohalines for Line D in Figure 17. The dashed line indicates the upper boundary to a bottom layer with temperature and salinity constant with depth.



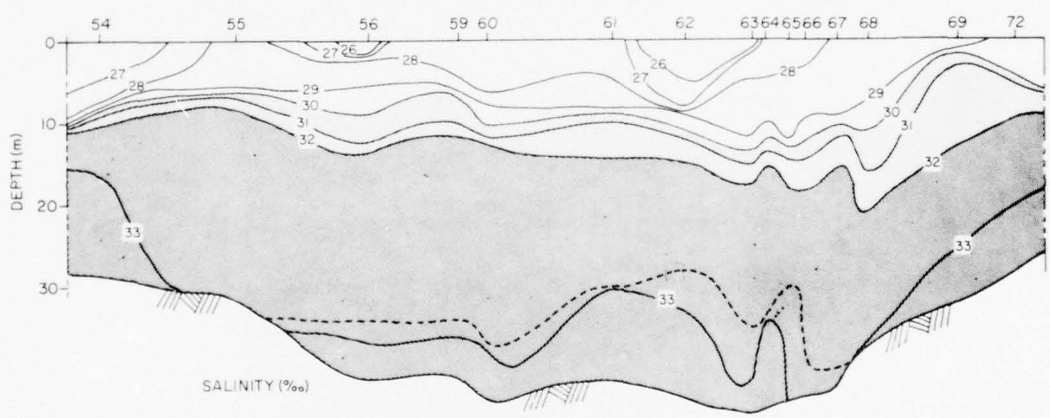


Figure 22. Isotherms and isohalines for Line E in Figure 17. The dashed line indicates the upper boundary to a bottom layer with temperature and salinity constant with depth.

A section for Line F is shown in Figure 23. The maximum temperature of the intrusion is far from shore and near the ice edge.

Line G was along the direction of the intrusion, which Figure 24 shows is a 10-m thick surface layer. Its lower salinity (28‰) could result from ice melt or river runoff, although the latter source is not supported by a lower salinity near the coast (see Lines E and F).

Line H extended the farthest up the coast, ending near the Kuk River at Wainwright (Figure 25). Beyond Station 118 the water is only slightly warmer than the freezing temperature. The surface salinity is low (27‰), but no lower than at 100 miles out from the coast; therefore the effect of the river outflow is not visible.

B. Intrusion

A diagram of the maximum temperature of the intrusion is shown in Figure 26. Isothermal lines show the transition between the 9°C water entering the strait and the -1.7°C water remaining from the winter cooling. The line for the 6°C intrusion the previous year (data were taken about two weeks earlier in the season) has been plotted to show that the intrusion was much later (or less) in 1975 than in 1974.[1]

A review of the conditions off Wainwright near the first of August during the past several years is presented in Table I. The maximum temperature observed is a measure of the advancement of the intrusion.

Table I. Maximum temperature off Wainwright near 1 August.

Year	Max. Temp. (°C)	Reference
1971	4	8
1972	6	11
1973	3	1
1974	3	1
1975	2	this rpt.

The 1975 intrusion appears to be far behind that of previous years. It has a north-heading branch, as was observed in 1971, which apparently is accentuated if the ice is closed in along the coast between Wainwright and Barrow.

A comparison of Stations 37 and 81 (Figure 27) shows a 4-day change in the intrusion--an increase in temperature at all depths, an increase in salinity in the upper half, and a decrease in salinity in the bottom

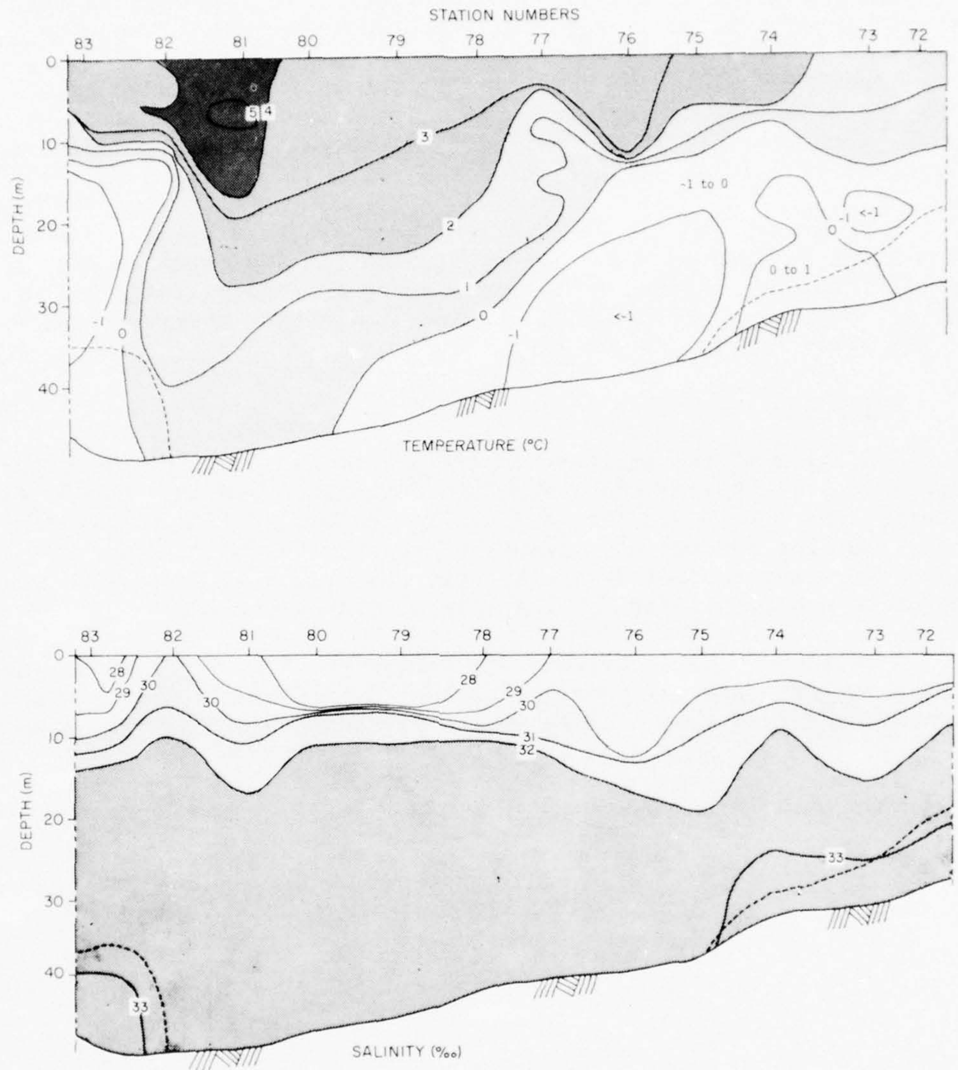


Figure 23. Isotherms and isohalines for Line F in Figure 17. The dashed line indicates the upper boundary to a bottom layer with temperature and salinity constant with depth.

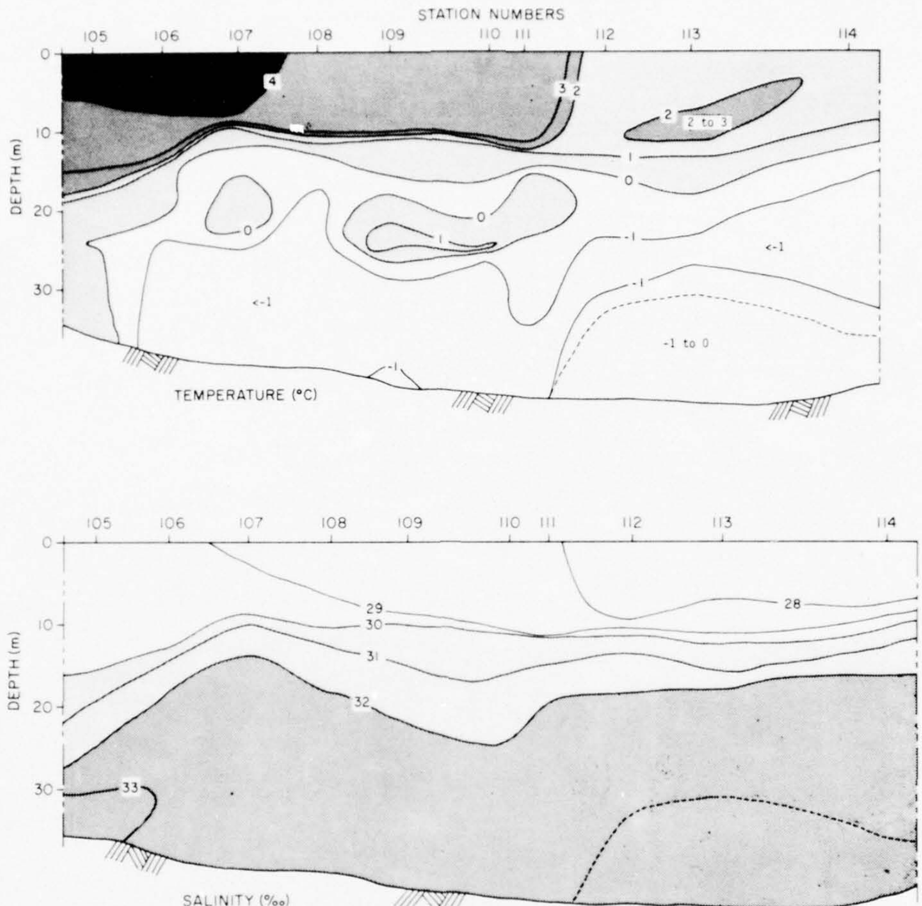


Figure 24. Isotherms and isohalines for Line G in Figure 17. The dashed line indicates the upper boundary to a bottom layer with temperature and salinity constant with depth.

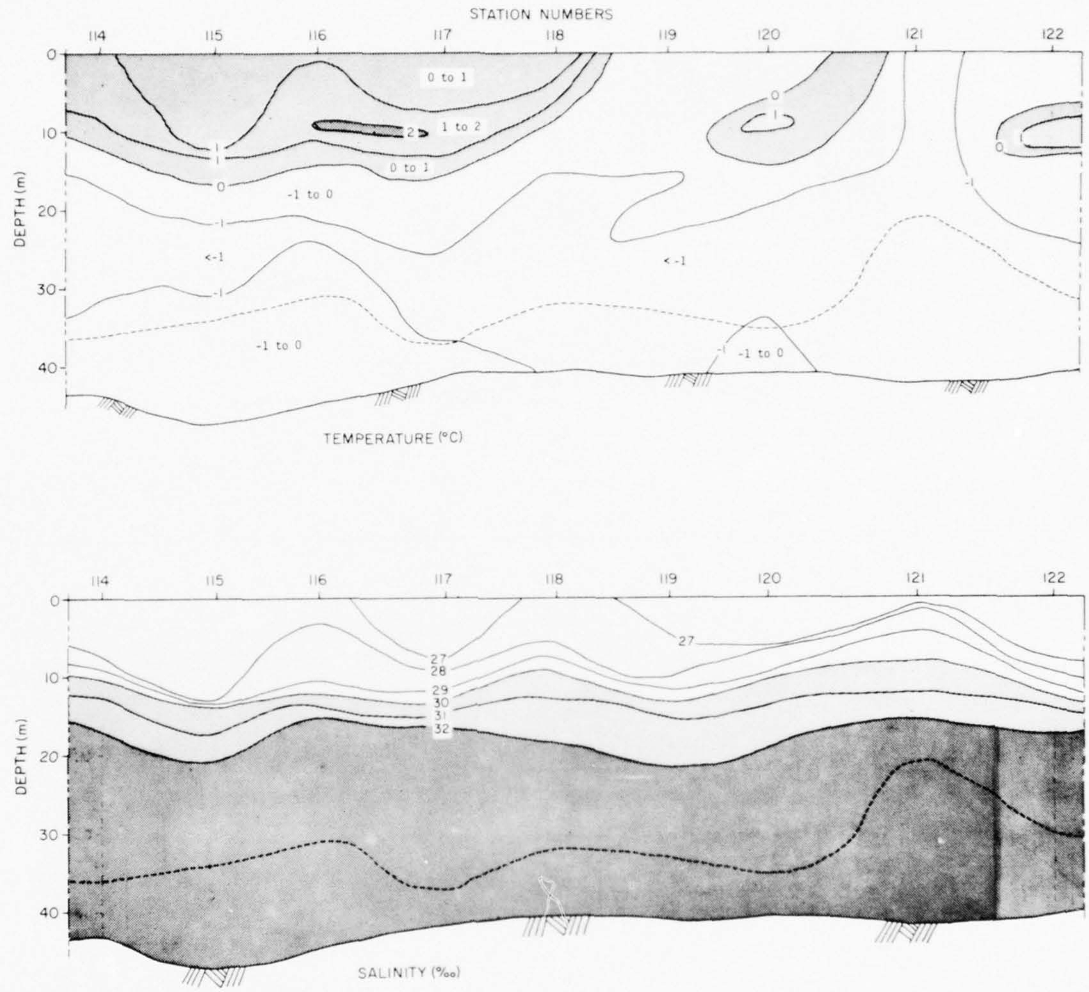


Figure 25. Isotherms and isohalines for Line H in Figure 17. The dashed line indicates the upper boundary to a bottom layer with temperature and salinity constant with depth.

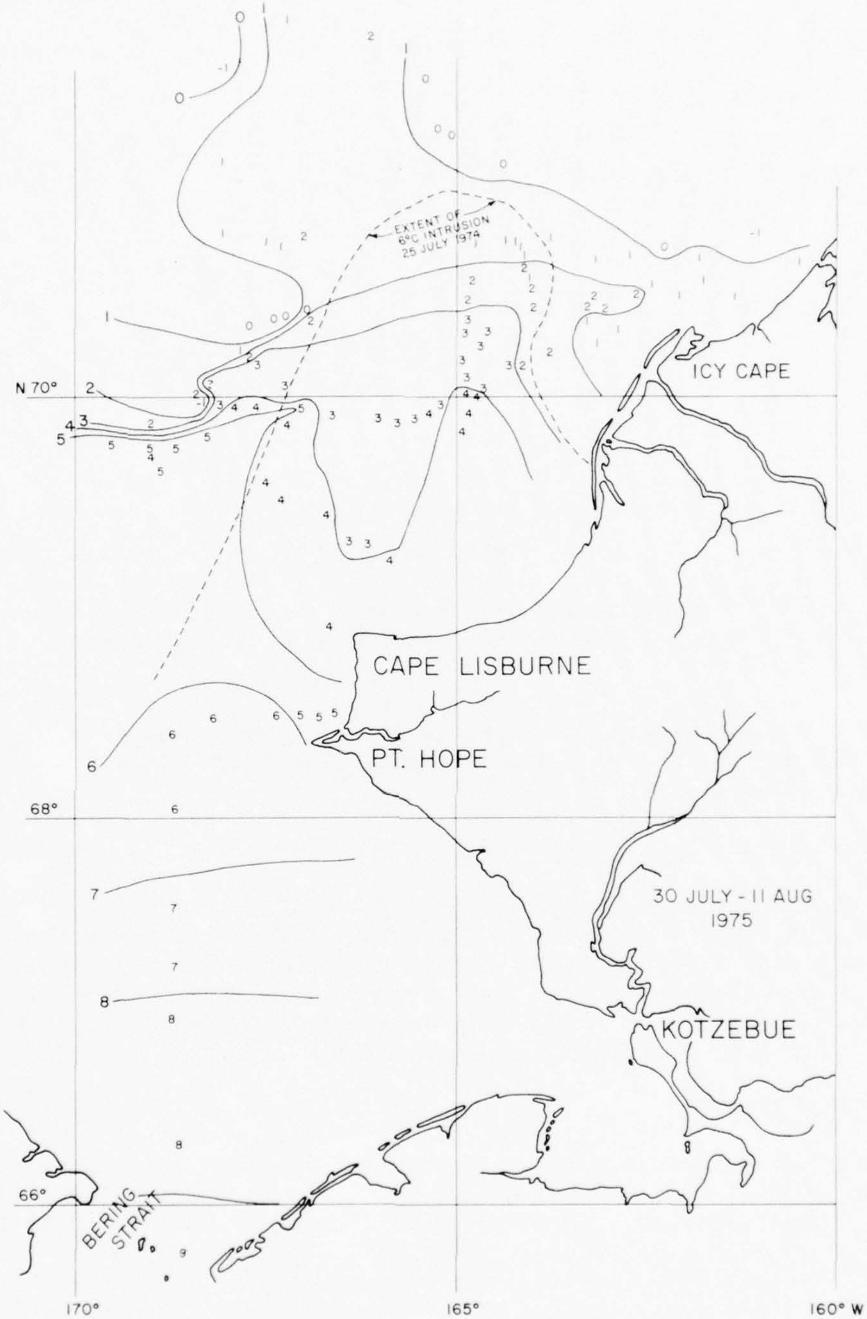


Figure 26. Isotherms of the maximum temperature recorded for each station.

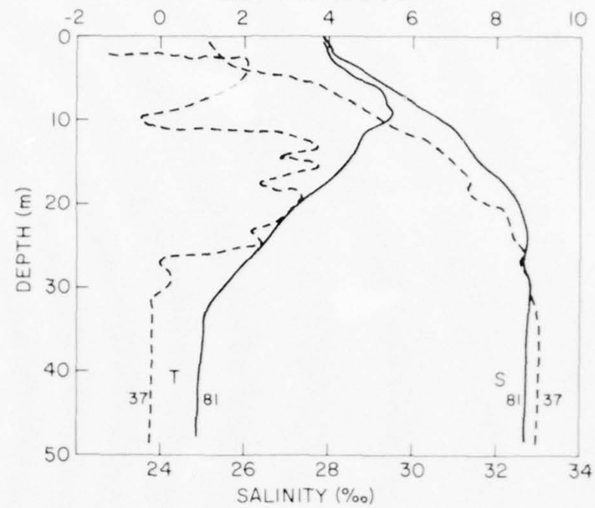


Figure 27. A comparison of properties at two stations taken at approximately the same location 4 days apart.

third. Other crossing comparisons do not show much change (e.g., Station 63 vs 115, and 76 vs 103). Apparently the intrusion comes around Pt. Hope and heads directly north.

C. Low-Salinity Surface Layer

A diagram of surface salinity is presented in Figure 28. The low-salinity (24-28‰) surface layer extends to the north and northwest beyond the boundary of the measurements, and thus beneath the ice edge. In 1974 the low-salinity surface layer was confined to a strip as shown by the dashed line for S = 30‰. The surface layer is the result of melting ice with some contribution from river runoff.

D. Bottom Layer

Many of the profiles show a bottom portion that has nearly constant temperature and salinity. Figure 29 shows the temperature and salinity of this layer for every station where it appears. North of Cape Lisburne the temperature of the layer is below zero and varies with location. The salinity is near 33‰, varying from 32.6 to 33.6‰. The salinity conforms with Chukchi Sea winter water, but the temperature is higher by 0.5 to 2°C. This water mass appears so uniform that it must have been well mixed at some time or formed in a manner that produces uniformity. It is too warm to be a relic of winter water. The July 1974 profiles[1] show no evidence of a warm bottom layer.

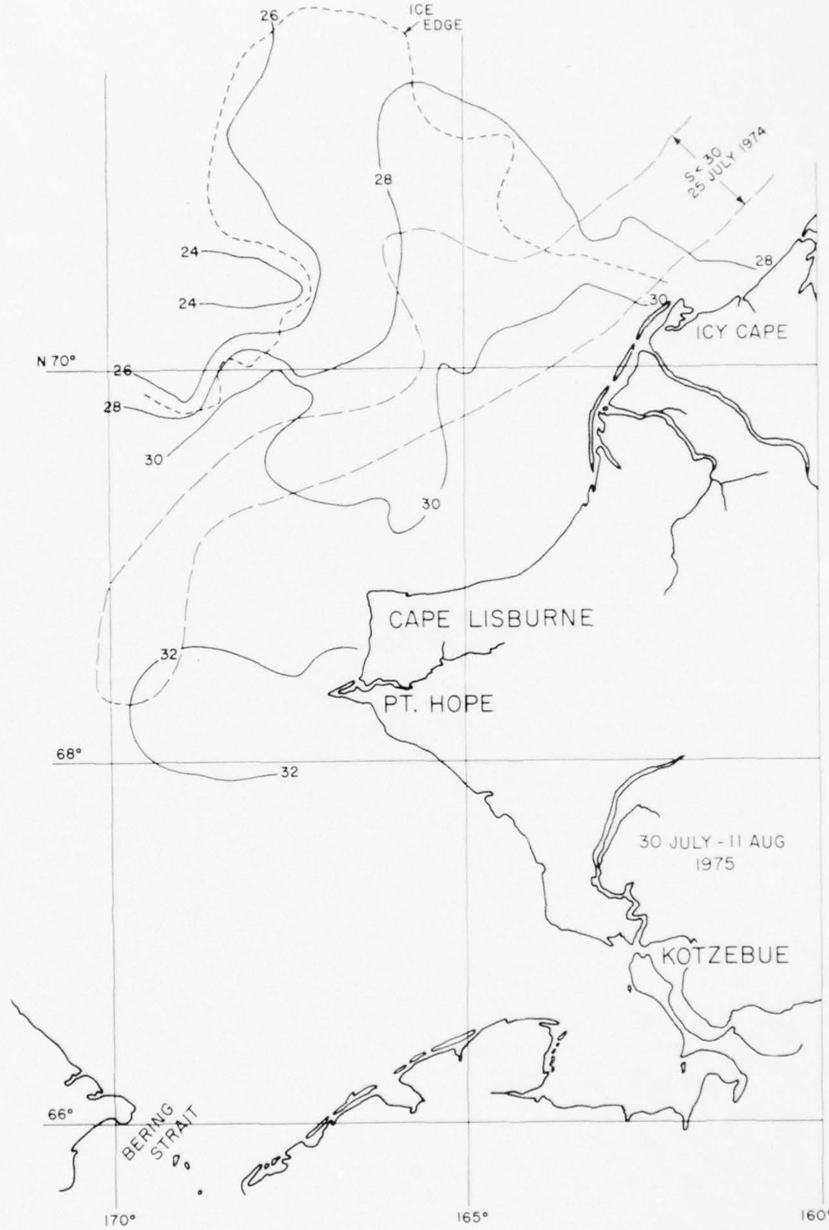


Figure 28. Isohalines for surface salinity. The area observed in July 1974 with salinity less than 30‰ is shown for comparison.

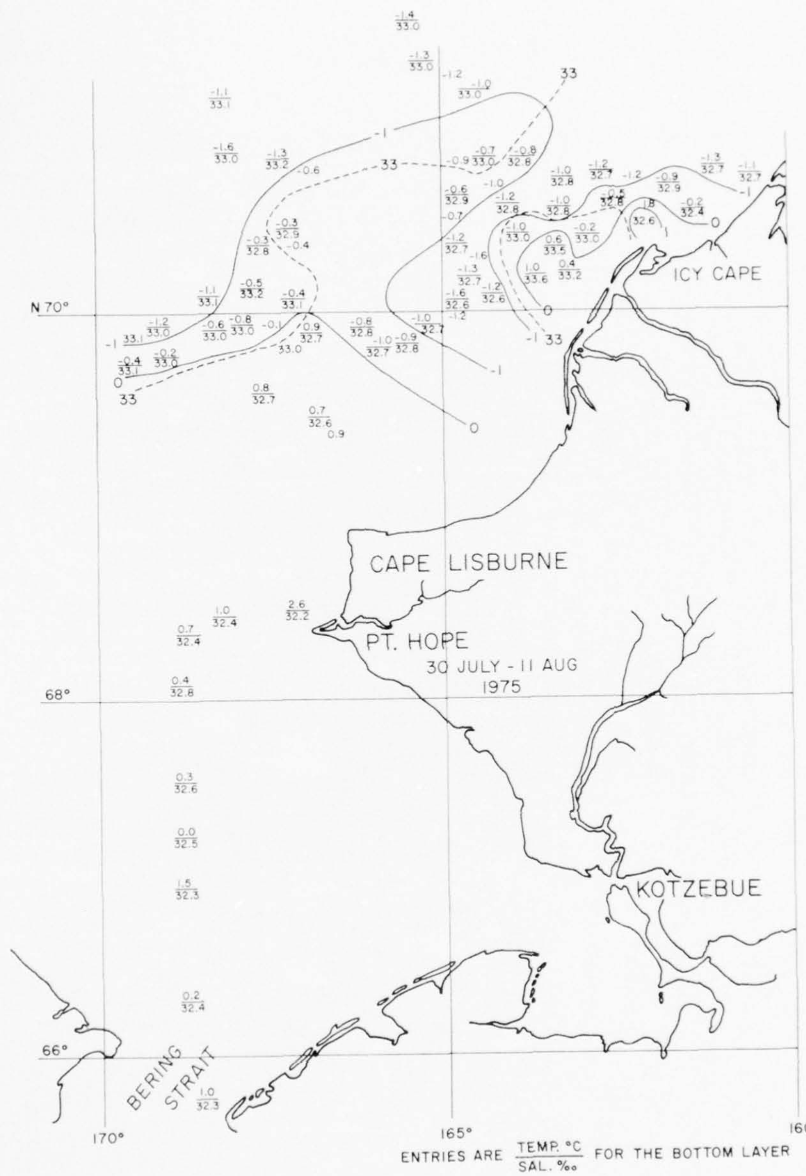


Figure 29. Temperature and salinity for all bottom layers with constant properties.

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In the central portion of the area, where the intrusion from the south predominates, the bottom layer has the lowest salinity (<32.9‰) and the salinity profile merges gradually into the constant salinity bottom layer. The outer area and an in-shore area near Icy Cape have higher bottom salinities with a sharp break at the top of the bottom layer. This suggests that the bottom water in the central area is part of the recent intrusion while the boundary water has been there for some time.

Several possible sources of the high-salinity bottom layer should be considered:

(1) *An uprising from the deep Beaufort Sea into and through the Barrow Canyon with subsequent movement southwesterly along the coast during a reverse coastal current.* This may not seem feasible because of the large quantity of water and the long distance from the Beaufort Sea. However, there are several observations in favor of such a flow. The wind stress was southerly in the strait and westerly at Barrow from 21 April to the end of May. The satellite photographs for this period (Figure 30) show a southerly movement of ice through the strait (evidenced mainly by the pileup of ice on the north side of St. Lawrence Island and the open water on the south side) and open water along the coast southwest of Barrow. The measurements in April (Figure 6) showed the presence of water with a salinity of 33‰ and temperature of -1.4°C to a depth of 40 m off the mouth of the Barrow Canyon. Atmospheric pressure records (see Figure 31) for the spring and summer months show several periods in April and May when the pressure was high enough to produce a southwesterly flow as indicated by the measurements of current by Mountain.[3,7] After mid-June the pressure excess was smaller and the expected flow was northeastward. A bottom layer formed by southwesterly flow from the Beaufort Sea must have arrived prior to the arrival of the intrusion from Bering Strait because the intrusion appears to have displaced the bottom layer in the central portion (where S < 33‰ in Figure 29).

(2) *A submergence of high-salinity water formed in shallow regions during freezeup.* When the surface freezes, the salinity of the underlying water increases. The shallower the water, the greater the increase. (For example, note the salinity of 34.08‰ observed off Wainwright in April 1972 (Figure 56, page 66) compared to the salinity of 32.6‰ observed[8] in deeper areas.) If freezing continues, the water eventually attains a near-freezing temperature throughout and the salinity becomes constant with depth. In shallow areas along the coast, the salinity might reach 34 or 35‰; being heavier than the surrounding water, this highly saline layer would eventually flow into the deeper areas farther from shore. This layer

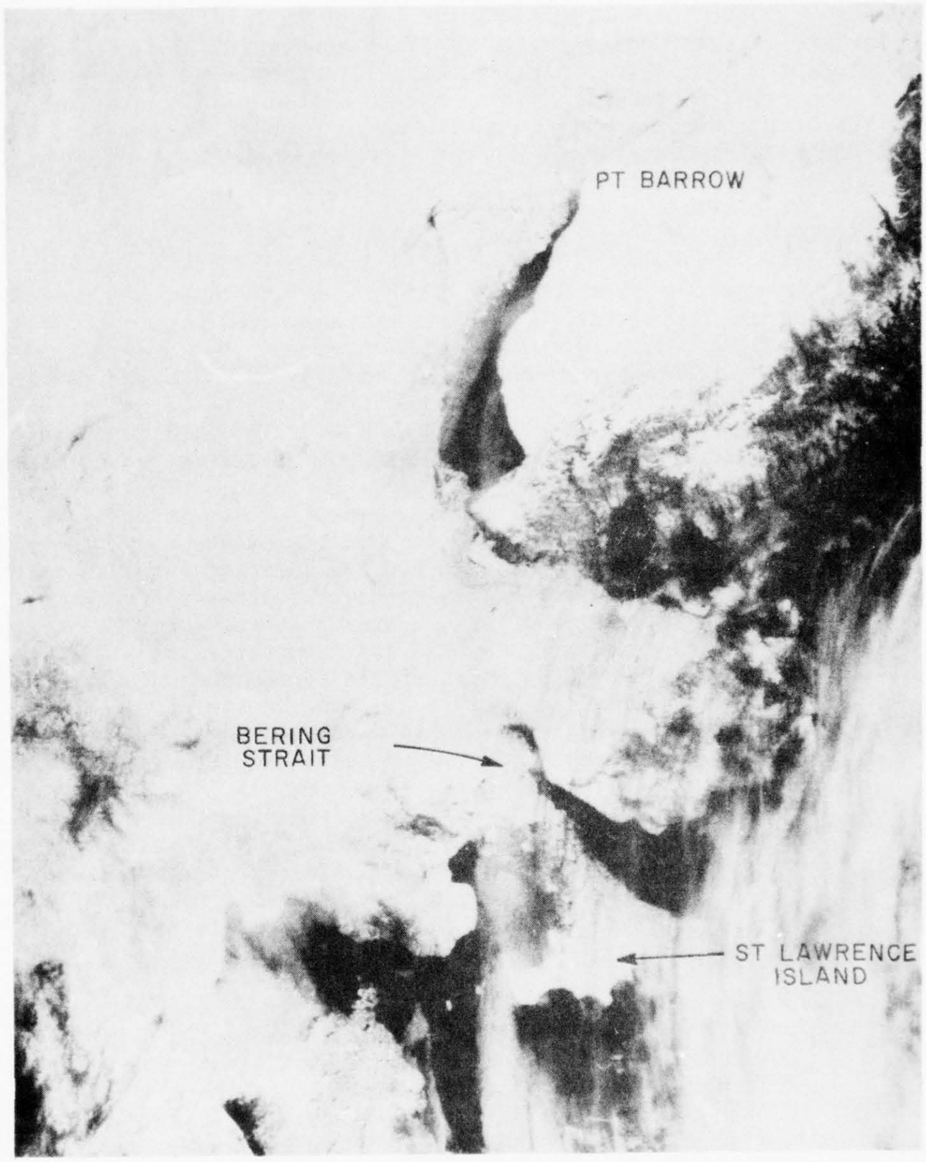

Figure 30. Satellite photographs of Bering Strait and St. Lawrence Island showing southerly flow of ice.

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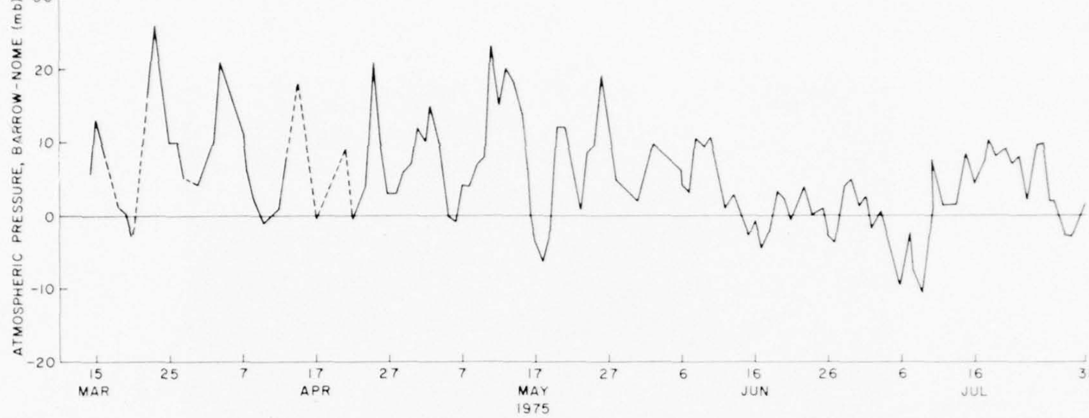


Figure 31. Atmospheric pressure records for March-July 1975. The pressure for Barrow less the pressure at Nome is plotted for each day.

would normally remain near freezing. However, satellite photographs taken in May (Figure 32) show that the ice was well off the coast for most of the month. Assuming a net solar heat gain at the surface of 100 cal cm^{-2} per day,[9] the average temperature of the upper 20 m would rise 1.6°C. We postulate that the winds that held the ice off shore could have also kept the saline shallow water in place; when the ice moved back to the shore in June, the warmed saline water was allowed to settle into the lower depths to form the warm bottom layer. Such a process would account for the variation in temperature observed because the temperature of the layer would depend on the depth and slope near shore. The constancy of the properties with depth is expected when heavier water sinks downward.

(3) *An early summer (say, mid-June) intrusion through Bering Strait.* The Bering Sea south of the strait has a salinity of about 33‰ in the summer and in some years its temperature starts rising in May. If the water in the strait warmed to 0°C while maintaining a salinity of 33‰, it could have intruded along the coast, sunk to the bottom because of its greater density, and mixed with the existing -1.7°C water in the Chukchi Sea to form temperatures like those shown in Figure 29. The bottom layers would then have had about 6 weeks to diffuse into a uniform state. However, we would expect a gradual increase in temperature toward Bering Strait if the warmer water came from there; such an increase is not apparent (when looking for such a trend in Figure 29, the recent intrusion must be ignored).

Figure 32a. A satellite photograph of the open water along the coast for 14 May 1975.

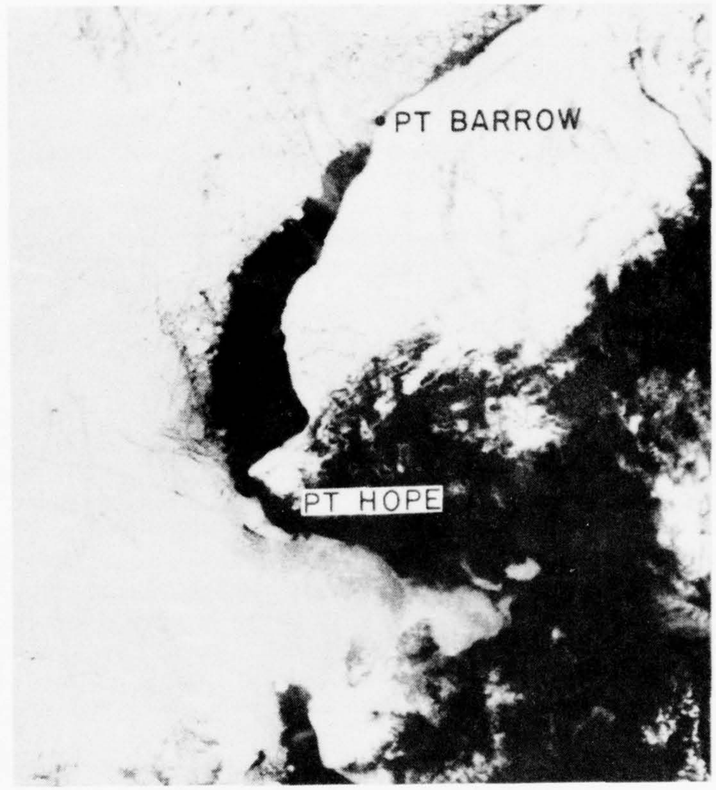


Figure 32b. A satellite photograph of the open water along the coast for 29 May 1975.

(4) *A mixture of items (1) and (2).* The high salinity, cold water ($S = 35‰$, $T = -1.7°C$) formed in the shallow areas could mix with the layer moving southwestward from the Beaufort Sea ($S = 32.5‰$, $T = -1.25°C$) to form a bottom layer with a salinity of 33.3‰, and a temperature of -1.4°C. By August such a layer could be quite uniform and stable.

The high salinity of the bottom layer seems best explained by freezing in adjacent shallow waters. The higher temperature could come from the Bering Sea, local ice-free shallow areas, or the Atlantic water in the Beaufort Sea. The local source of heat is preferred because: (1) the warm bottom layer is an unusual occurrence, and so was the long period of open water along the coast, (2) the temperature varies with location with no along-the-coast trend, and (3) the other sources require a sequence of events that, although shown to be possible, are unlikely and unverified.

The hypothesis that the bottom layer comes from the Bering Sea agrees in part with the conclusion by Coachman and Barnes[10] that the layer of cold water observed at about 150 m depth in the Beaufort Sea is a mixture of Siberian shelf water and Bering Sea water. Both require considerable northerly flow through Bering Strait in the winter. However, evidence is presented (see Section IX) that the northerly flow through the strait is far from continual in the winter, suggesting that Bering Sea water should not be considered as a source of the bottom layer observed in July 1975, nor as a contribution to the cold layer in the Beaufort Sea. The Beaufort Sea cold layer may be maintained solely by shelf water entering through Barrow Canyon and along the edge of the shelf as illustrated in Figure 4. This layer would warm with time, or distance from the shelf, as it appears to do in the measurements reviewed by Coachman and Barnes.

VI. SURVEY OFF BARROW, NOVEMBER 1975

Oceanographic measurements were taken from a helicopter from 23 October to 6 November 1975. Only a few stations were taken because of difficulties in arranging flights (e.g., competing programs, uncertainties in the weather, and the safety requirement that a second aircraft accompany the flight).

A. Profiles

The temperature, salinity and density profiles obtained northeast of Barrow during this period are listed in Table II. Currents are estimated from the observed wire angle as the probe was lowered. The station locations are shown in Figure 33, and the profiles for each station are presented in Figures 34 to 41.

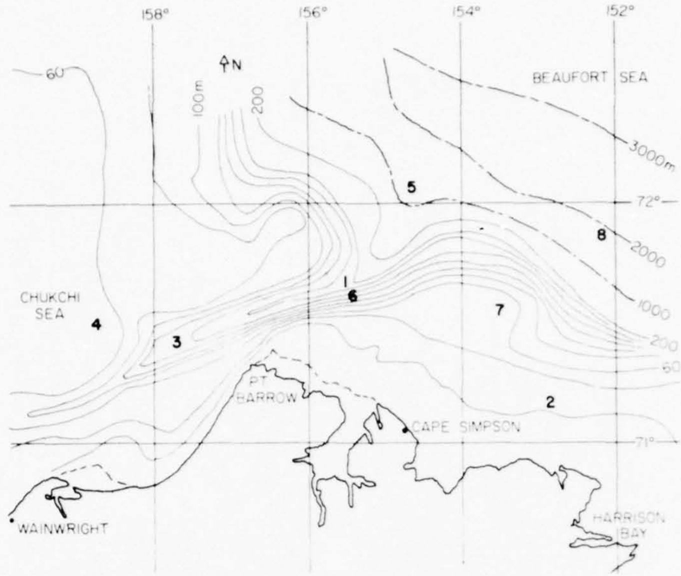


Figure 33. Station locations for the fall survey, 23 October-6 November 1975.

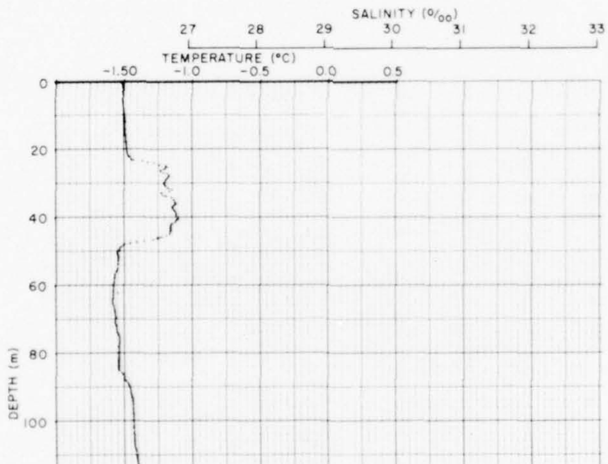


Figure 34. Temperature profile for Station 1, 23 October 1975.

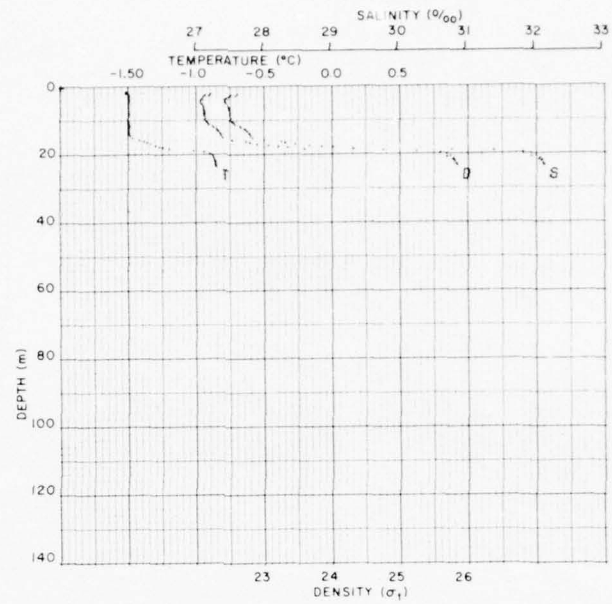


Figure 35. Temperature, salinity and density profiles for Station 2.

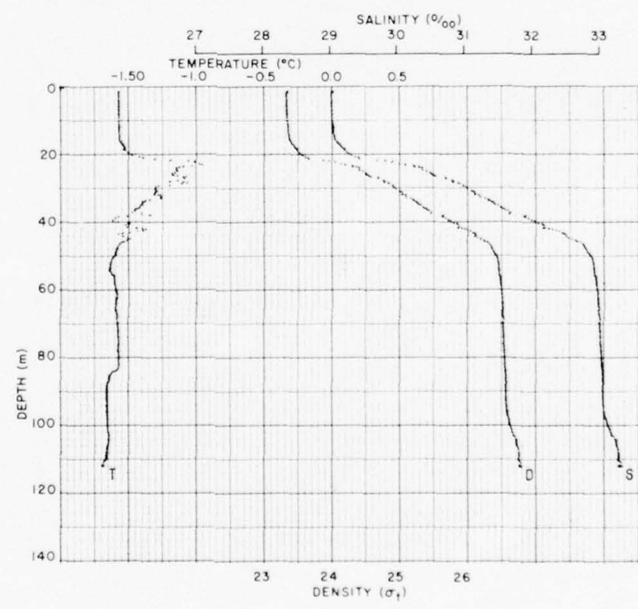


Figure 36. Temperature, salinity and density profiles for Station 3.

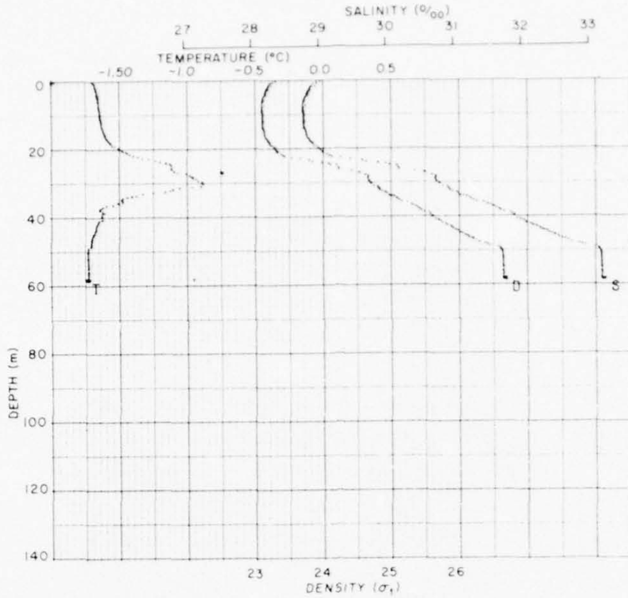


Figure 37. Temperature, salinity and density profiles for Station 4.

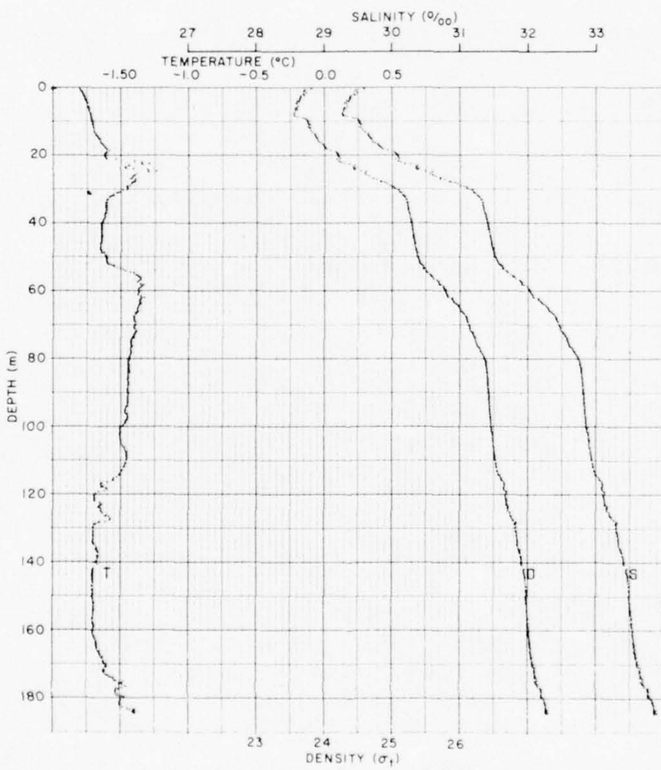


Figure 38. Temperature, salinity and density profiles for Station 5.

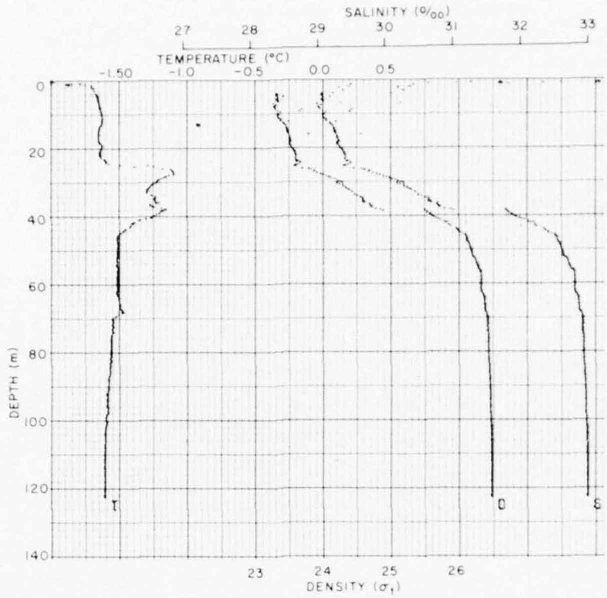


Figure 39. Temperature, salinity and density profiles for Station 6.

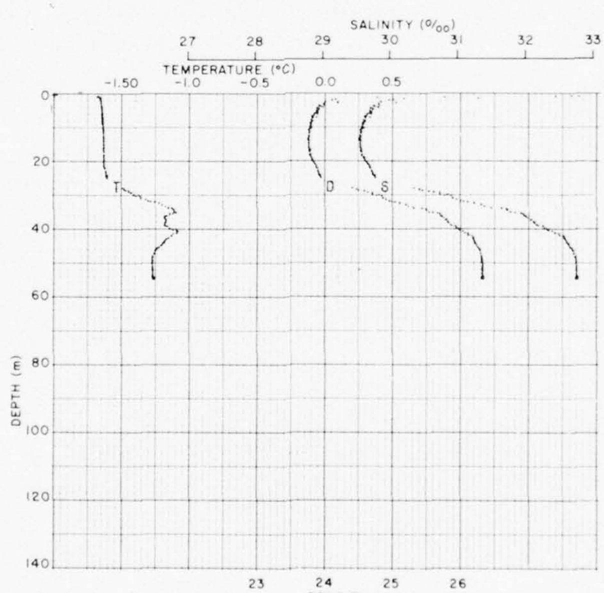


Figure 40. Temperature, salinity and density profiles for Station 7.

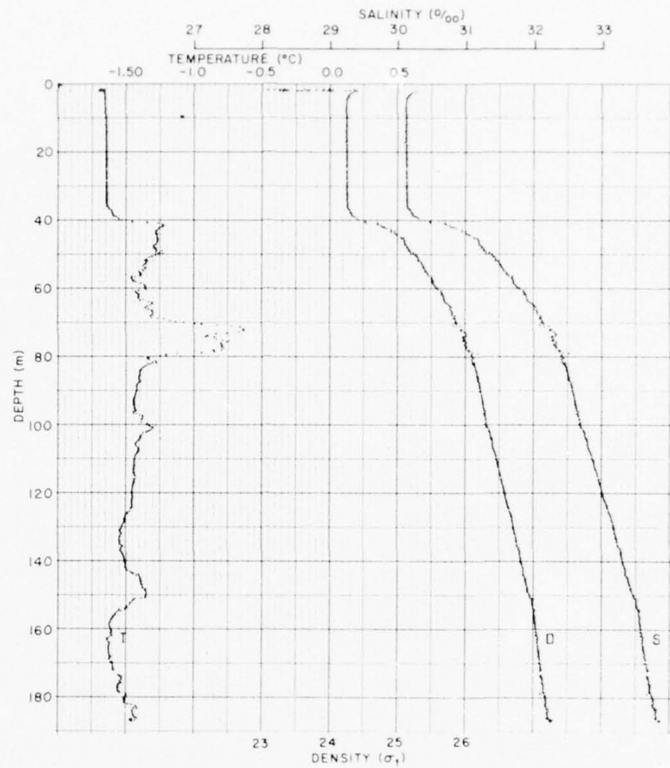


Figure 41. Temperature, salinity and density profiles for Station 8.

Table II. List of measurements.

Station	Date	Local Time	Remarks
1	Oct 23	1655	Conductivity failed
2	26	1345	
3	31	1018	Current to north
4	31	1525	No current
5	Nov 1	1520	No current
6	5	1210	Current to north
7	5	1345	No current
8	6	1215	No current

B. Discussion

Examination of the profiles reveals several features of interest:

1) Surface cooling has produced a surface layer with constant temperature and salinity. This layer becomes thicker and of higher salinity to the east, reaching a depth of 40 m and a salinity of 30.2‰ at Station 8.

2) Below the surface layer is a layer of warmer (-1°C) water which appears to be the remains of the summer intrusion of water from the Bering Sea. This layer most likely extended to the surface before the autumn cooling began.

3) At the deepest stations (5 and 8) is a mid-depth layer (60-120 m) of slightly warmer water (-1.3°C) which is usually present in the Beaufort Sea. It is apparently replenished each summer by the intrusion of warmer water from the Bering Sea into the Chukchi Sea. An example of a recent input to this layer is the water between 70-80 m at Station 8 with a temperature of 0.7°C and a salinity of 32.3‰. This water must have come through the Barrow Canyon at the forefront of the summer intrusion (which was exceptionally small in 1975).

4) The isohalines rise in the shallow areas as seen in Figures 35 and 40 for Stations 2 and 7. From Station 8 to Station 7, for instance, the 32.5‰ isohaline rises 40 m. A similar slope to the isohalines was observed in May 1975 (see Section IV).

5) There is a region of near-freezing water off the mouth of the canyon at a depth of 120-160 m that appears to be little different than the water existing there in May.

6) A bottom layer at 50-60 m (see Figure 37) at Station 4 has the properties often found in the lower depths of the Chukchi Sea and recently found as a spring flow over the edge of the shelf 70 miles farther north.

In our earlier discussion of the May profiles, we stated that the cold water found off the Barrow Canyon (at depths from 100-160 m) had flowed from the Chukchi Sea through the Barrow Canyon during the winter and spring. We assumed that prior to this flow the temperature off the mouth of the canyon was the same as that of the Beaufort Sea a few miles away. By November this water should have been replaced by the summer intrusion from the Bering Strait or warmed by contact with the warmer layers above and below it. Instead, the November profiles show little change from the May profiles at these depths. Apparently the intrusion did not extend into this region this year.

The TS diagrams for the eight stations are presented in Figure 42. Curves representing the temperature limits for the spring 1975 data (from Figure 9) have been included as dashed lines for comparison. Considerable warmer, less saline, water has appeared in the upper regions since the previous spring. The spring condition will be regained when the upper regions cool and the surface freezes, causing an increase in salinity. The lower portion of Station 4 remains very close to the near-freezing condition of the Chukchi Sea in the spring. The lower portions of the deeper profiles are intermediate between the Beaufort limit and the freezing line, as they were in the spring. They will probably continue to warm until the Chukchi Sea cools and again drains into this region (see Section III).

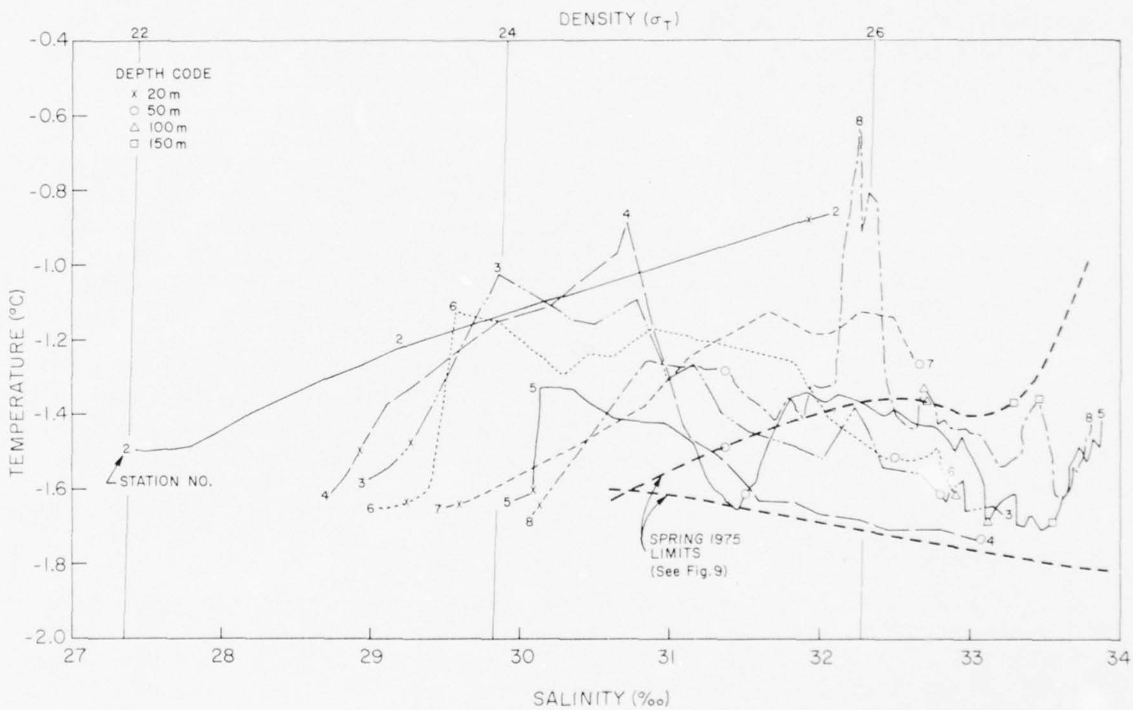


Figure 42. Temperature-salinity diagrams for the eight stations of the fall survey.

VII. COASTAL CURRENT OBSERVATIONS, 1971-1975

A. Arctic Studies

Camps were established on ice floes in the Chukchi Sea in the summers of 1971 and 1972.[8,11,12] These camps drifted southward toward the coast until they entered the Alaskan Coastal Current whereupon they moved rapidly northeastward, parallel to the coast. Temperature and salinity profiles were measured routinely from the ice floes as well as from the icebreaker that supported the camps. Icebreaker cruises were also made across the Chukchi Sea almost to Wrangel Island to obtain temperature and salinity distributions along the entire length of the Marginal Ice Zone; another cruise along the same line was made in August 1973. A cruise took place from Nome to Barrow in July 1974, and short cruises off Barrow and Wainwright were added in September 1974.[1] These measurements outlined the summer intrusion of warm water northward into the Chukchi Sea each year. The intrusion varied considerably from year to year. It was most extensive in 1972, which may be related to anomalous conditions that occurred in the Pacific Ocean that year.[13,14]

Ice camps were established north of Barrow in the springs of 1974[1] and 1975, and routine measurements of temperature, salinity and current were taken. Oceanographic surveys were made of a large area northeast of Barrow in April and May 1975 using a recently developed lightweight profiler operated from a ski-equipped Cessna aircraft. These measurements contributed new information about water movements in the Barrow Canyon in the spring.

The acquisition of 1974-75 NOAA-2 satellite photographs,[15] both visible and infrared, provided a record of the ice coverage and water surface temperatures that proved very helpful in following the ice movement and the gradual progression of the intruding warm water along the coast.

B. Winter Conditions

There is ample evidence that the northern part of the shallow Chukchi Sea cools to the freezing point each winter. Measurements off Barrow in April 1972[12] showed freezing temperatures out to 120 km except for an isolated layer in the Barrow Canyon with a temperature 0.3°C warmer. This near-freezing water still existed below 30 m only 90 km northwest of Barrow as late as August. The relic of winter water at the lower depths had a salinity of about 34‰.

C. Summer Conditions

The warm intrusion usually follows the coastline after the ice pack has moved away from the shore, although sometimes it spreads northwest toward Herald Island and forms a distinct surface layer about 10 m thick.

This warm water (6-10°C) passes Barrow in late summer and has been observed in the Beaufort Sea by Paquette and Bourke[4] and by Hufford,[16] where it tends to descend beneath low salinity surface layers and be diffused by the large eddies created as the current continues past Pt. Barrow into the influence of the Beaufort gyre.

Chukchi Sea conditions in the summer vary greatly according to the distance from the coast. In the northern part, the near-freezing water column, still ice covered, is warmed at the surface and diluted by melting ice. The farther from the surface, the more winter-like the water becomes, with relics of undiluted winter water remaining along the bottom in places. In the southern part, there is a layer of the warm intrusion on the surface and often a mixture of intrusion and winter water at the lower depths. Near the coast, the intrusion predominates and often forms a strong current that is concentrated along the coast.

VIII. CONCENTRATION OF THE COASTAL CURRENT

The coastal current can be observed by oceanographic measurements, by ice floe drift, and in satellite photographs. Evidence is provided here that the current along the coast is often a narrow, concentrated stream extending from the Bering Strait to the Beaufort Sea.

A. Ice Floe Drift

Ice floes were occupied in early August in both 1971 and 1972 in an area northwest of Barrow. In both cases, the floe drifted slowly southward until it encountered the coastal current and was then swept rapidly northeastward along the coast and past Barrow into the Beaufort Sea as shown in Figure 43.

Both years the coastal current was encountered about 30 km off the coast near Wainwright, and the drift of the occupied floe changed from southward to northeastward. As the ice floe moved closer to the coast, the drift rate increased, reaching a maximum of 150 cm s^{-1} in 1971.[8] In 1972, the maximum drift speed was 100 cm s^{-1}, but a measured current relative to the flow of 25 cm s^{-1} to the northeast indicates the true current was 125 cm s^{-1} parallel to the coast.[11] During both periods the winds were light and variable. The floe drift was influenced by the wind, but the general pattern, southerly toward the coast and then northeasterly along the coast, persisted.

B. Temperature and Salinity Distributions (1971-1974)

Each icebreaker cruise has included lines perpendicular to the coast at Barrow and Wainwright (see Figure 43). The sectional plots of isotherms and isohalines that follow show the changes in these properties from the coast out to the ice pack.

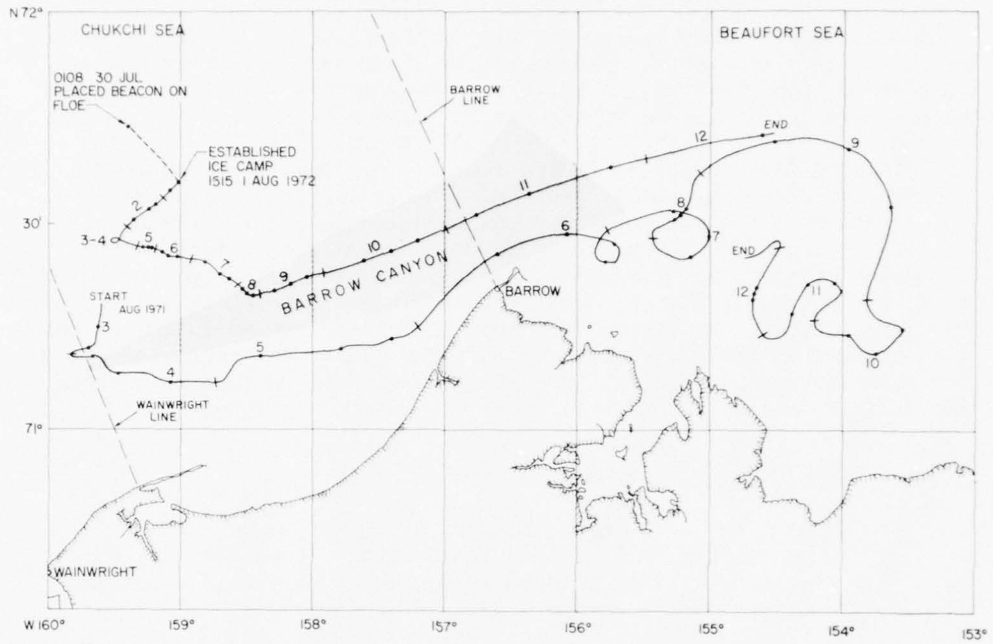


Figure 43. Drift tracks of the occupied ice floes in 1971 and 1972. A dot represents 6 hours and a cross line marks the end of the day.

Figure 44 shows the conditions off Barrow on 22 August 1971. At that time, the intrusion, which had a maximum temperature of 2°C, extended out 50 km. Near the coast, the isohalines, which predominate in control of the density, rose to give an isopycnal slope of 0.0017 from the middle of the Barrow Canyon to the coast.

In August 1972, the intrusion had a higher temperature. Isotherms for a section out from Barrow on 20 July (Figure 45) show a concentration of 0°C water along the coast. After three days of strong easterly winds, measurements off Wainwright (Figure 46) showed 5°C water near the surface 18 km from the coast; the 0°C water along the coast was less deep, as if the wind had caused it to rotate upward and outward. We suspect that the isopycnal slope observed along this coast may be related to the offshore wind.

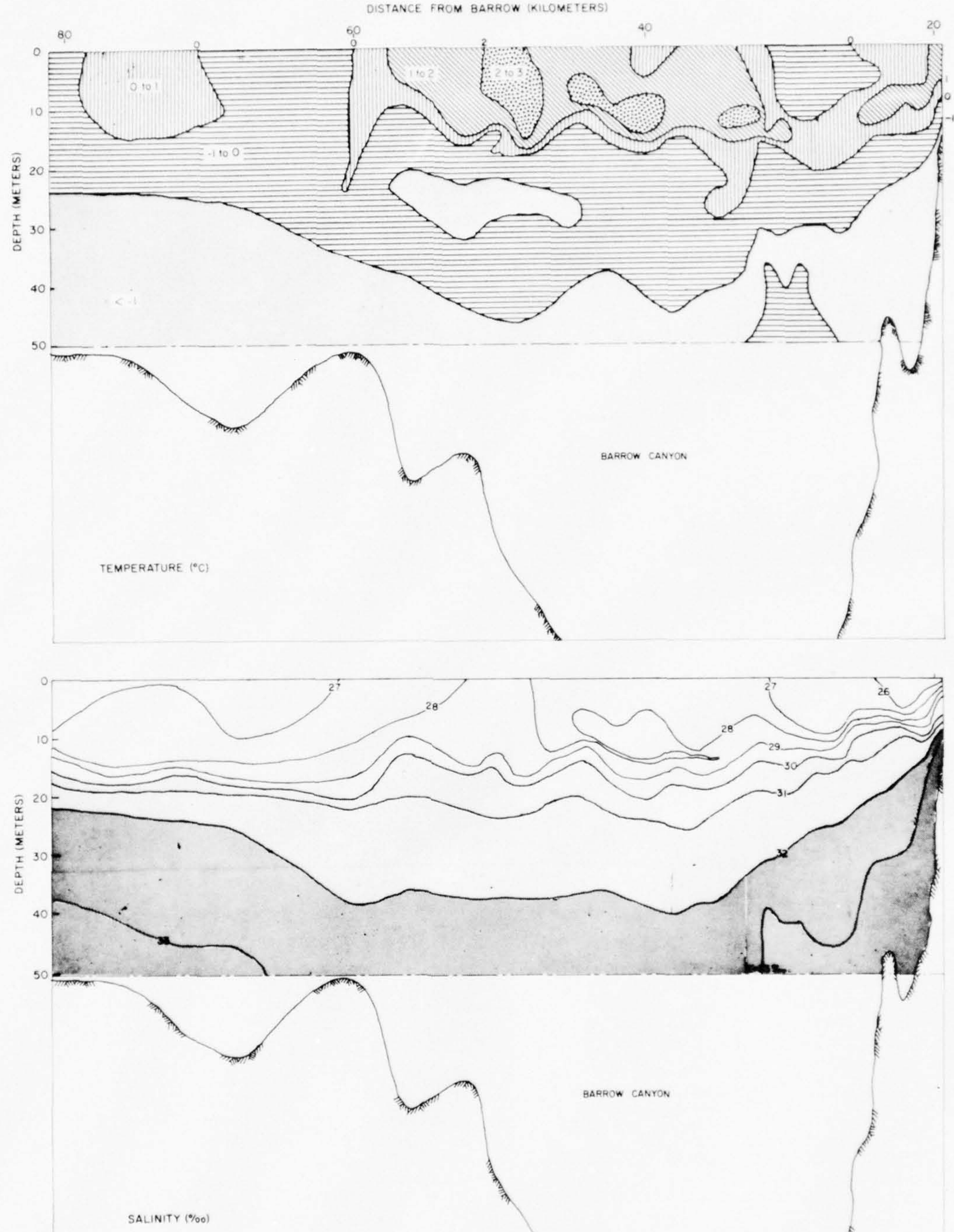


Figure 44. Isotherms and isohalines for a section along the Barrow Line, 22-23 August 1971.

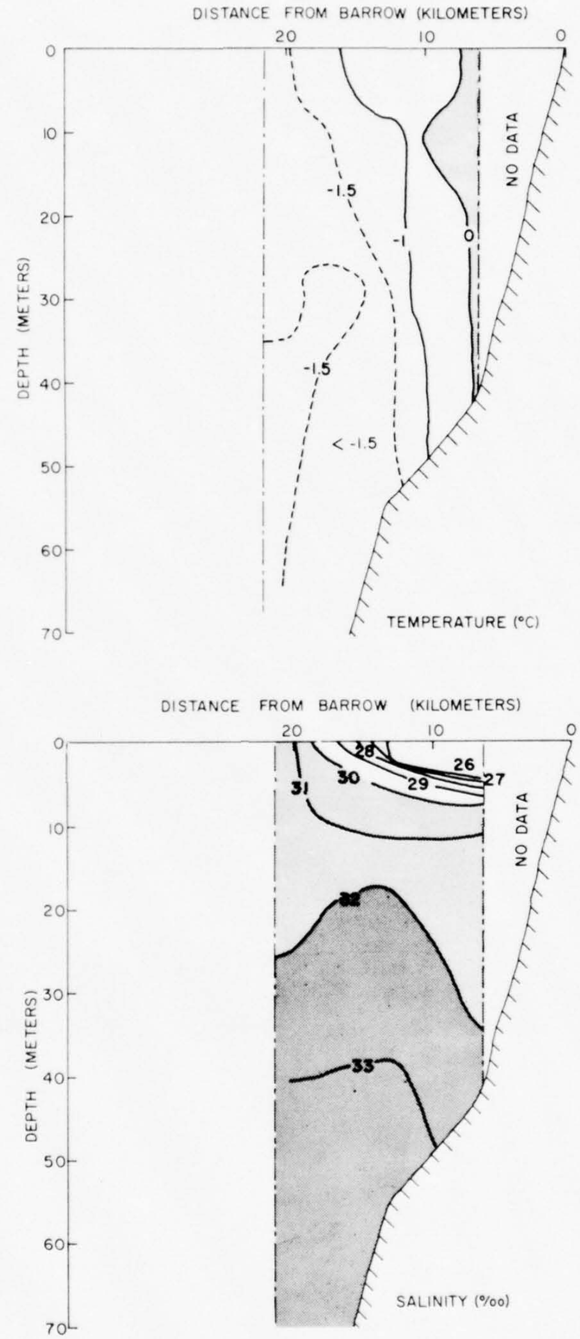


Figure 45. Isotherms and isohalines for a section along the Barrow Line, 20 and 21 July 1972.

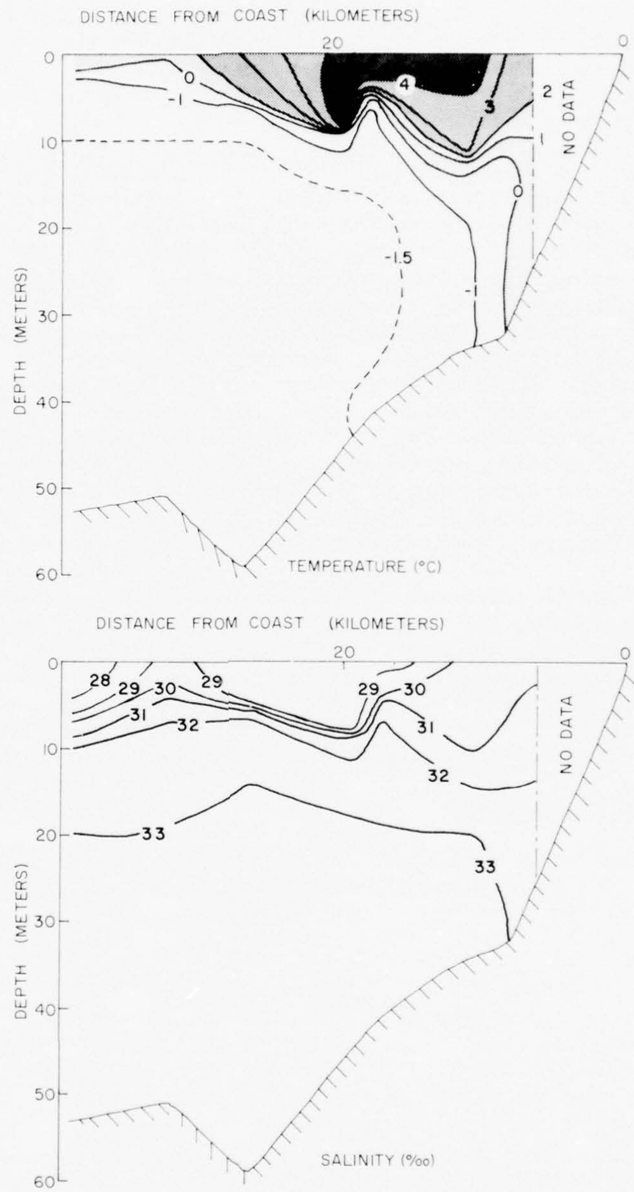


Figure 46. Isotherms and isohalines for a section along the Wainwright Line, 24 July 1972.

On 13 August 1972, a section off Barrow (Figure 47) showed 2-8°C water existing within 18 km of the coast. By this time, the Wainwright section (Figure 48) showed a similar concentration in the upper 10 m extending to 30 km off shore.

Sections in 1973 showed similar results. The Wainwright section taken on 4 and 5 August (Figure 49) shows 1-3°C water confined within 18 km of the coast. A later section taken at Barrow on 10 August 1973 (Figure 50) shows 2-4°C water within 18 km of the coast; the salinity of this water is much lower than that of the water farther out. Measurements farther south off Icy Cape in July 1974 (Figure 51) showed the intrusion to be concentrated 75 km off the coast. Sections taken in September 1974 off Barrow and Wainwright (Figures 52 and 53) revealed the likely maximum of the intrusion for the year. At that time, 6-8°C water extended 100 km off Wainwright and much farther along the Barrow Line than the Barrow Canyon; at the lower depths, however, the intrusion was concentrated mainly over the canyon. The Barrow section showed a layer of cold water developing at the surface, and the Wainwright section showed a cold layer above the canyon, as if it had come up the canyon floor and been carried by its momentum into the warm waters above.

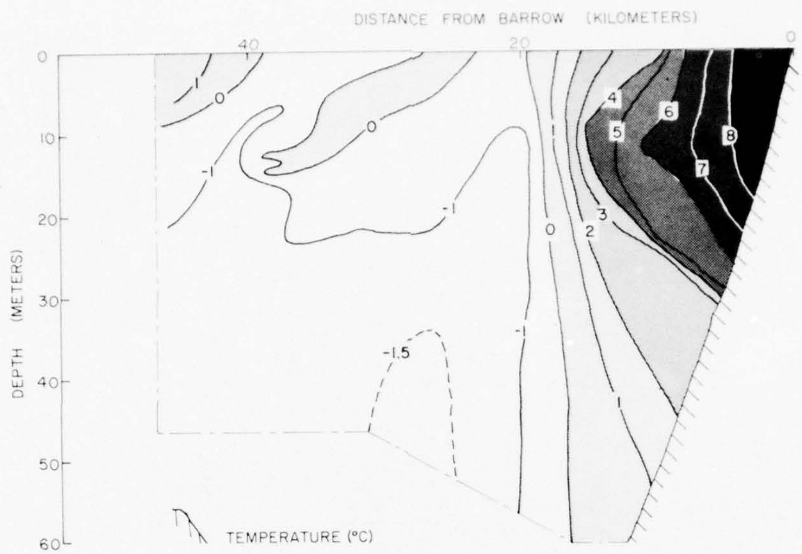
A comparison of isopycnal slopes (which can be inferred from the isohaline slopes) near the coast in 1971 and 1972 (Figures 44-48) shows an upward slope toward the coast in 1971 and no distinct slope in 1972. In 1973, measurements off the northwest coast showed isopycnals sloping downward toward the coast (Figures 49 and 50). They also sloped downward in 1974 (Figure 52). A study of wind records during these summers should be made to examine the influence of the wind on the isopycnal slope.

C. Satellite Photographs

Photographs taken from the NOAA-2 satellite show the entire coastline and thus aid greatly in revealing the overall pattern of ice movement. The ERTS satellite photographs show more detail, but cover a smaller area.

ERTS-1 photographs for 7 and 8 March 1973 presented by Shapiro and Burns,[17] and reproduced here as Figure 54, clearly show a swath of broken ice extending from Pt. Lay to the Bering Strait. Strong north winds during the week prior to the photographs are believed to have forced the ice through the strait and caused the fracturing north of there. The current at the time is unknown.

Our purpose in presenting the photographs here is to point out that the path of the fracturing extends past Pt. Hope and Cape Lisburne to Pt. Lay, the northern extremity of the photograph. Such fracturing so far north along the coast must have causes other than the stress produced on the ice in the narrow strait. The fractured zone is 70 km wide



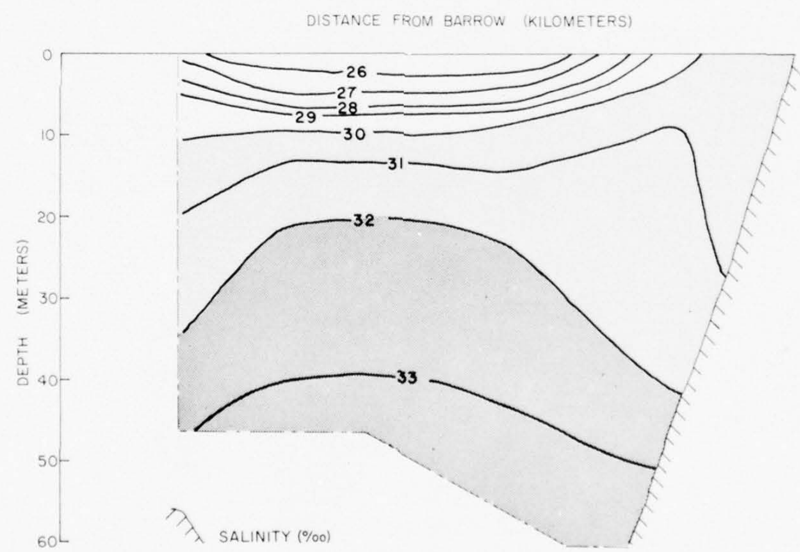


Figure 47. Isotherms and isohalines for a section along the Barrow Line, 13 August 1972.

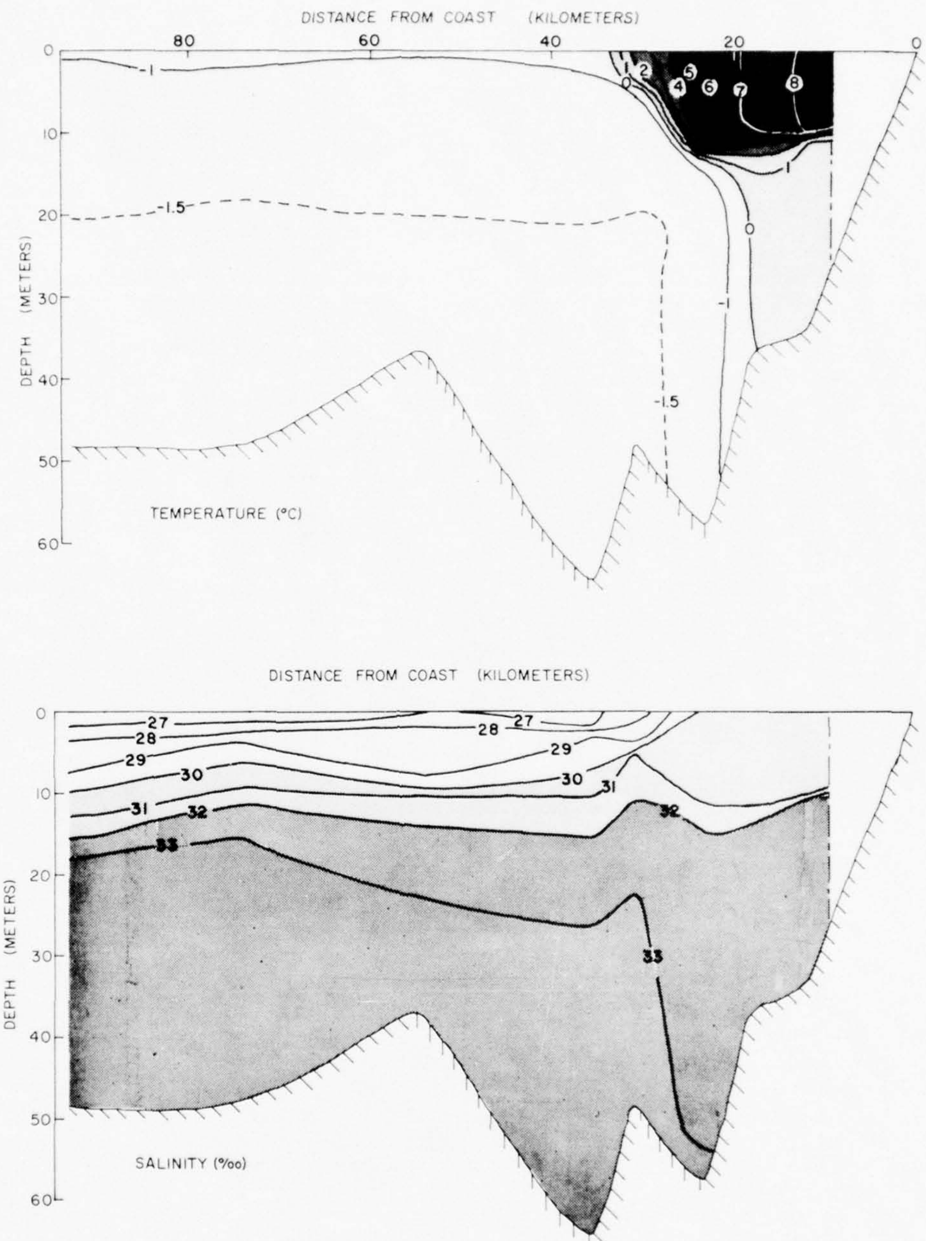


Figure 48. Isotherms and isohalines for a section along the Wainwright Line, 13-14 August 1972.

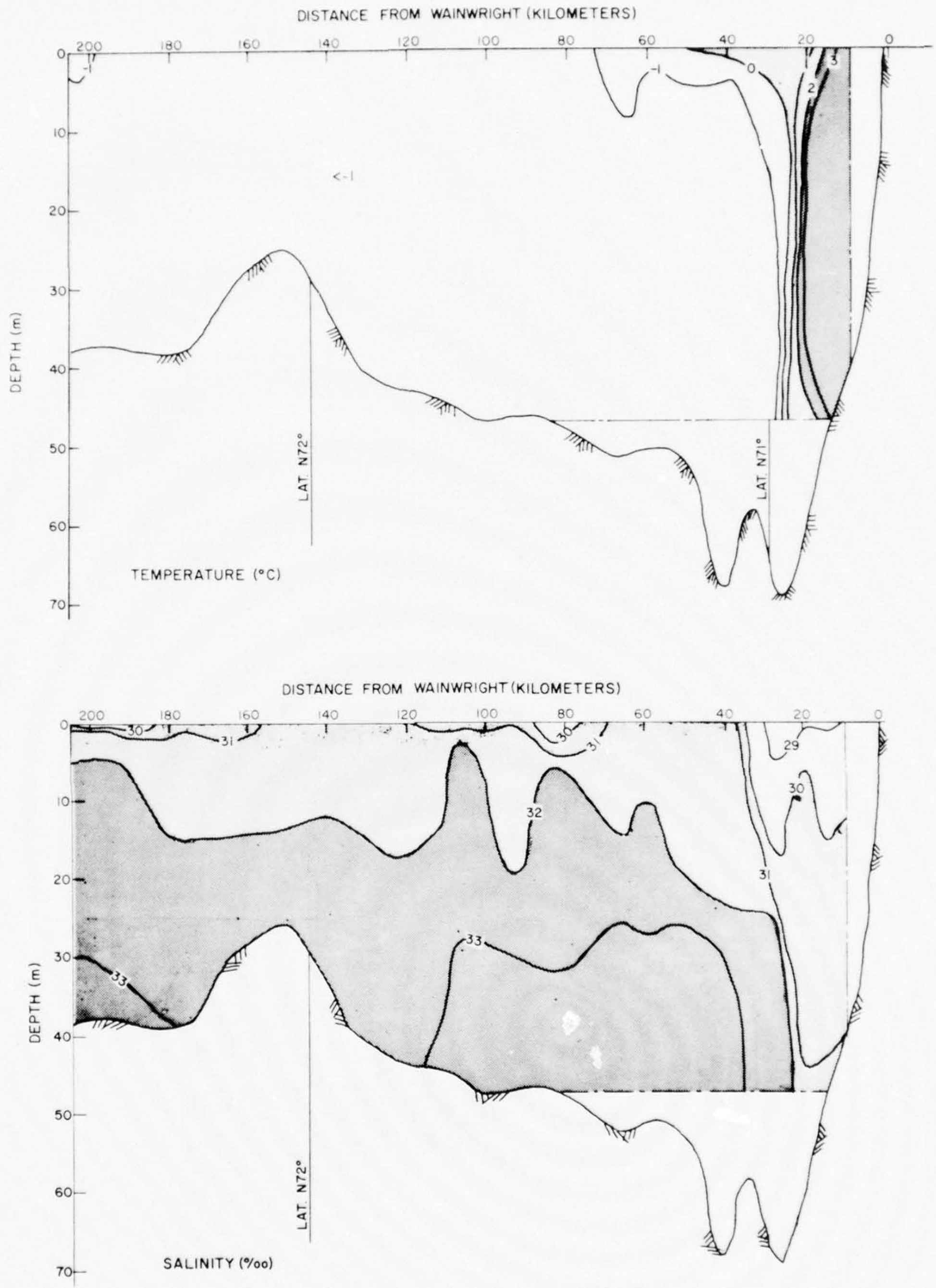


Figure 49. Isotherms and isohalines for a section along the Wainwright Line, 4-5 August 1973.

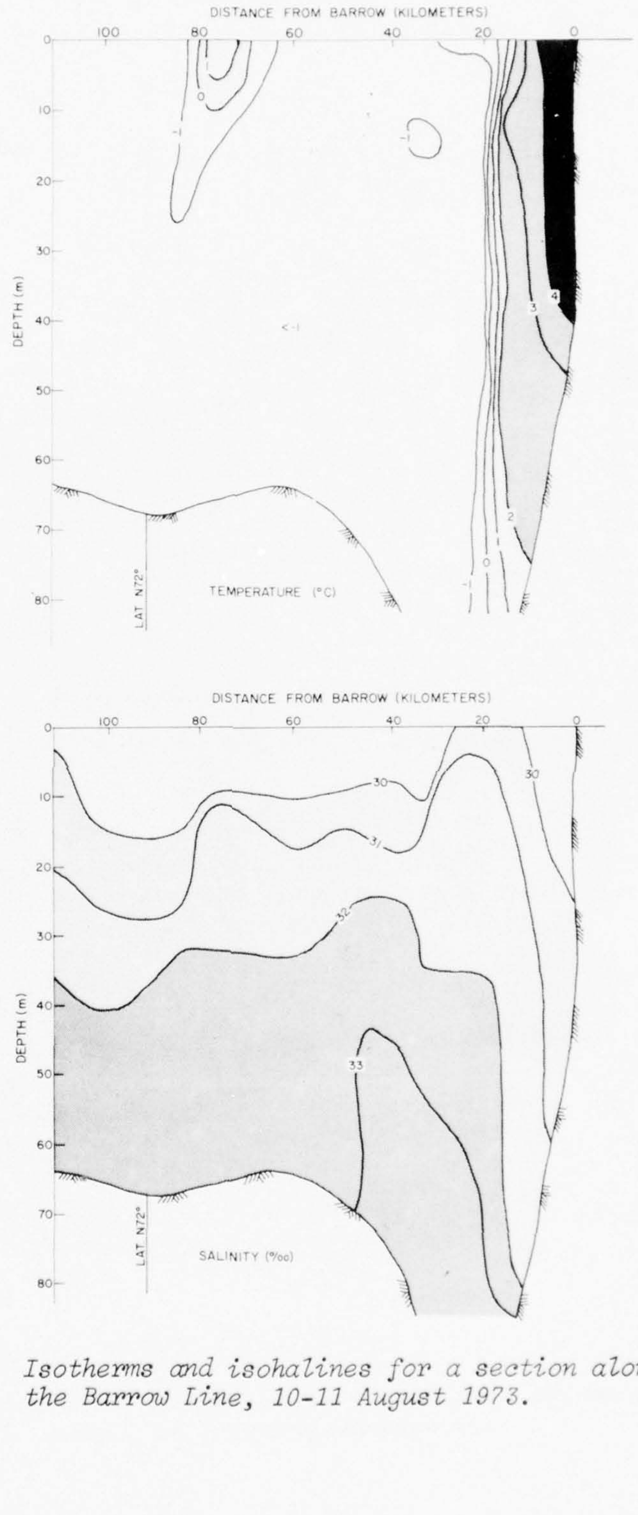


Figure 50. Isotherms and isohalines for a section along the Barrow Line, 10-11 August 1973.

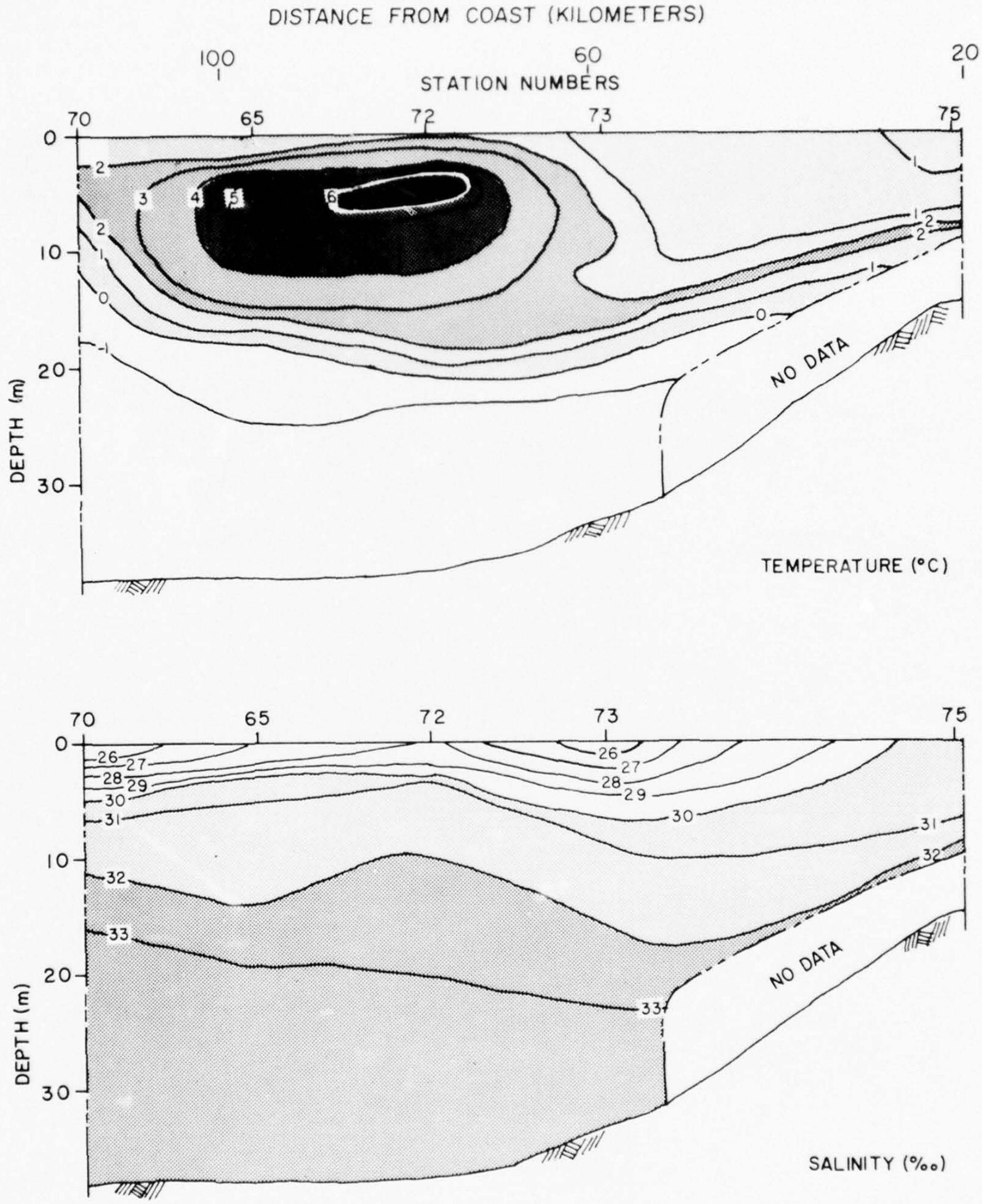


Figure 51. Isotherms and isohalines for a section along a line off Icy Cape, 21 July 1974.

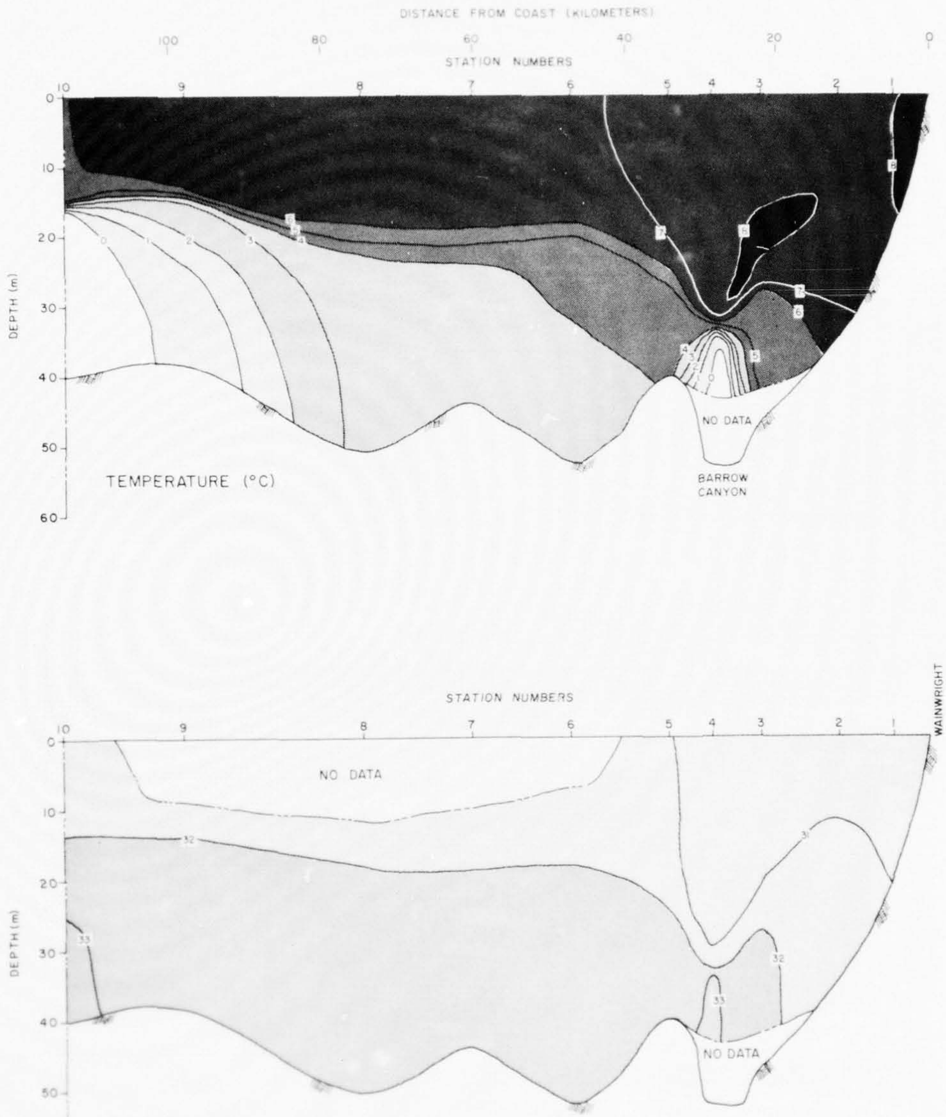


Figure 52. Isotherms and isohalines for a section along the Wainwright Line, 19 September 1974.

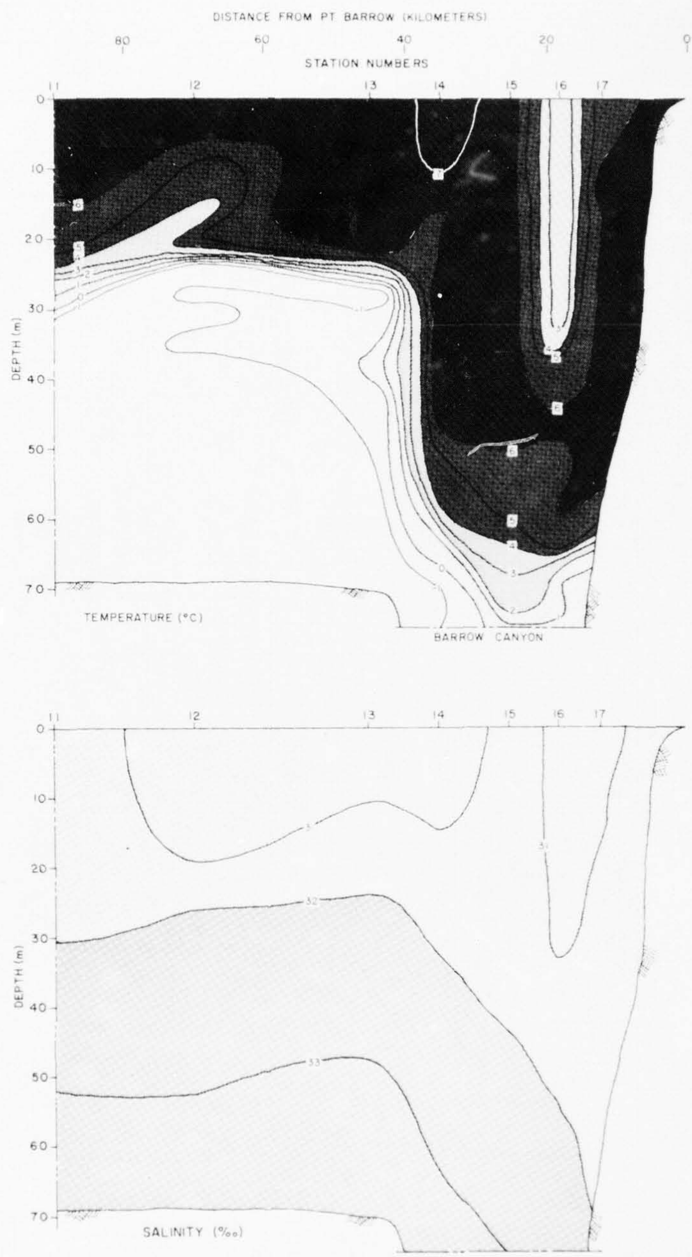


Figure 53. Isotherms and isohalines for a section along the Barrow Line, 20 September 1974.

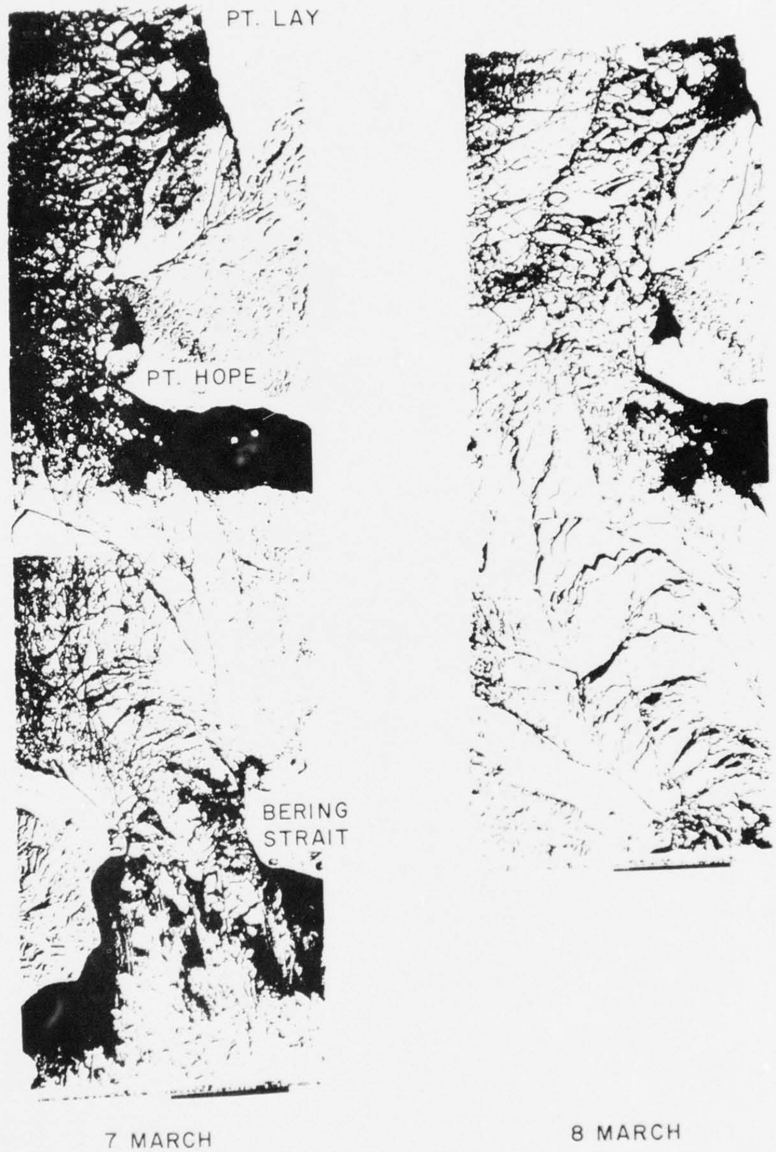


Figure 54. Satellite photographs of ice conditions from Bering Strait to Pt. Lay, 7 and 8 March 1973 (ERTS-1 MSS band 7 images through courtesy of Shapiro and Burns).

and appears to follow the path of the coastal current. We conclude that the fracturing must be related to such a current, either (1) because the current existed at that time, (2) because it existed during the previous month, causing some breakup, or (3) because it existed during freeze-up in late fall, retarding the formation of a solid pack and leaving, instead, an easily fractured zone along the coast. The last explanation is preferred in view of a similar fractured zone observed in the fall of 1974 (see far right photograph of Figure 55, a series of photographs taken by the NOAA-2 satellite in October 1974).

Figure 55 shows southeasterly movement of ice along the coast extending from Wainwright to 180 km northeast of Barrow, where the coast appears to blend into shore-fast ice. The series of photographs, with its identifiable ice floes, indicates a floe drift speed of 75 cm s^{-1} for the 4-day period. Other photographs (not shown) reveal that for a few days after this series the floes slow and nearly stop. During the next 4 days, the floes again move southwestward at nearly the same speed as before.

We cannot be certain whether this movement was caused by current or wind. Wind records for Barrow show a 5-knot east wind on the 14th, changing to the north at 10 kn on the 15th and 16th and continuing from the north at 5 kn on the 17th. These 4 days correspond to the southwesterly floe movement seen in Figure 55. A shift to south winds from 18 to 20 October coincides with the period that the floes stopped moving. A resumption of east winds on the 21st coincides with the resumption of floe movement southwestward. Despite the good correlation between floe movement and wind, the concentration of the movement in a strip along the coast seems more easily attributable to current.

IX. DIRECTION OF THE COASTAL CURRENT

In the preceding section, we showed evidence that the coastal current is usually a continuous flow from the Bering Strait to the Beaufort Sea--an "artery" connecting the Bering Sea and the Arctic Ocean. If this is true, then the direction of the flow may indicate the relative water level in these large bodies of water--whether it be caused by local differences in atmospheric pressure, local winds, or global ocean forces. The assumption has often been made that the coastal current flows northeastward most of the time. This is certainly true in the summer, but southwesterly flow has recently been observed in the other seasons. Although the transport may be small, the direction may be a strong indicator of climatic and oceanic conditions in the Arctic. In this section, we will present our observations, and reference the observations of other investigators, on the direction of flow of the coastal current.

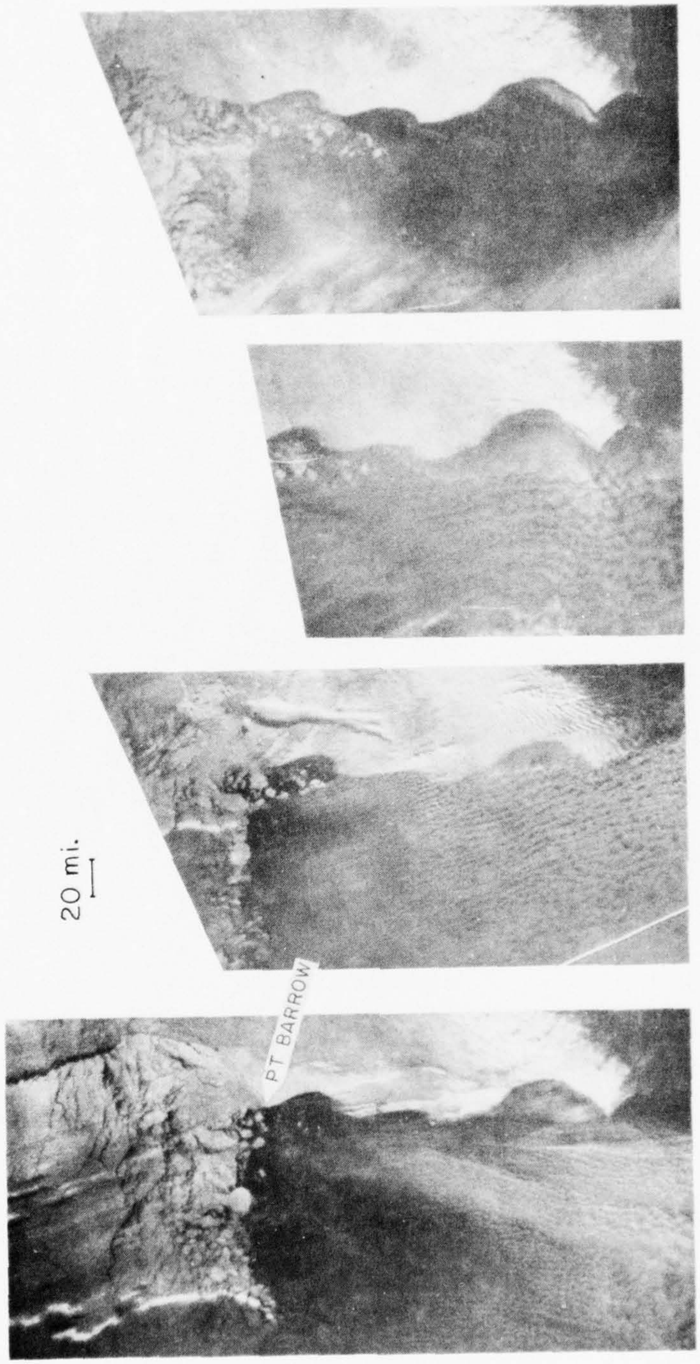


Figure 55. *Satellite photographs of ice conditions along the northwest Alaskan coast in October 1974 (NOAA-2).*

A. Current Meter Data

The best evidence of current direction is presented by Mountain[3,7] who reports on two current meters installed in the Barrow Canyon for the period 20 April through 18 August 1973. The measurements show the expected northeasterly current throughout the latter half of the period, but from 20 April to 20 June the current was southwesterly 28% of the time at a depth of 96 m and 22% of the time at a depth of 126 m. The southwesterly current was weaker than the northeasterly current. Mountain contends that daily variations are related to the atmospheric pressure gradient across the area. Temperature sensors attached to the current meters showed a sudden rise in temperature to 0°C during two periods of southwesterly current. Mountain states that this warmer water represents an upwelling of Atlantic water 150 m above its normal level.

B. September Conditions off Wainwright

Measurements off Wainwright in September 1974 (Figure 52) show a region of cold water extending up into the warm intrusion that usually lies above the Barrow Canyon in late summer. This appears to result from a flow southwestward up the canyon with sufficient momentum to carry the cold water up into the warm intrusion above. Measurements along the Barrow Line (Figure 53) show similarly cold water farther east at lower depths in the canyon. A northeastward flow could possibly bring water of the proper temperature and salinity from the lower depths of the Chukchi Sea, but a pileup of cold water above the canyon seems so unusual that such flow is considered very unlikely.

C. April Temperature Rise in Barrow Canyon

A measurement of the temperature profile west of Barrow on 29 April 1972 showed a layer with a maximum temperature of -1.4°C at about 30 m, and a temperature of -1.7°C for adjacent waters (see Figure 56). In light of the temperature profiles taken in mid-May 1975, it appears that this warmer water may have come from the Beaufort Sea; if so, a brief period of southwesterly flow through the canyon is indicated.

D. April Conditions off Barrow

An ice floe 50 km northeast of Barrow was occupied from 11-23 April 1974. During this period, with light winds from the northeast, the floe drifted 18 km southwestward. Current measurements on 22 April showed a current relative to the floe of 10 cm s^{-1} to the southwest at a depth of 80 m. At this time the floe was 32 km from Pt. Barrow and directly over the Barrow Canyon, and thus the measured current indicates a southwesterly flow of the coastal current.

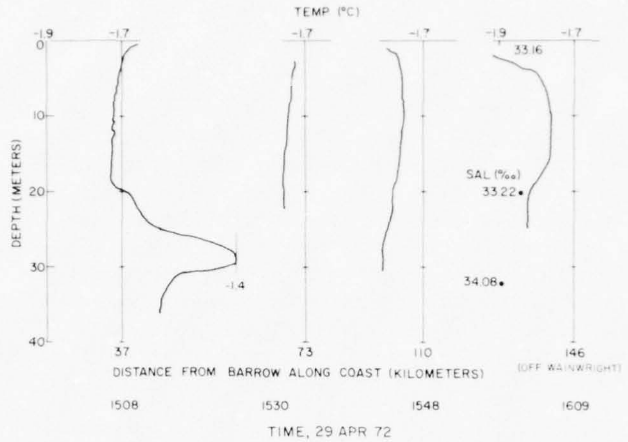


Figure 56. Oceanographic measurements off the Barrow-Wainwright coast on 29 April 1972. Reversing thermometer readings are plotted with the salinities written alongside.

E. Satellite Photographs

Current direction can sometimes be inferred from a single satellite photograph. If loose floes are held against the pack ice, either the wind or the current must be moving toward the pack. Often the wind can be estimated from cloud or fog formations. A series of photographs containing identifiable floes is more helpful because it shows both the direction and magnitude of floe movement.

The floe movements shown in Figure 55 for 14-17 October 1974 indicate a southwesterly flow. Wind is not the likely cause, because floes a few kilometers farther from the coast, although no longer attached to the pack, remain close to it.

Figure 57 is a winter satellite photograph taken on 2 January 1975 that indicates a southerly flow through the Bering Strait. The pileup of ice on the north side of St. Lawrence Island and the absence of ice on the south side indicate that ice has come south through the strait and passed on both sides of St. Lawrence Island. Wind records for Mys Uelen (see Figure 58 for location) were examined to determine if the ice movement could have been caused by wind. The winds during the first half of December were consistently from the north at 10 to 20 kn. During the latter half of December, the winds were moderate and from the north 60% of the time. Therefore, it is very likely that the ice conditions seen in Figure 57 were produced by the wind. Whether or not the water was also moving southward cannot be determined from the photographs, but in the shallow strait it seems likely that the wind would produce a southerly current.

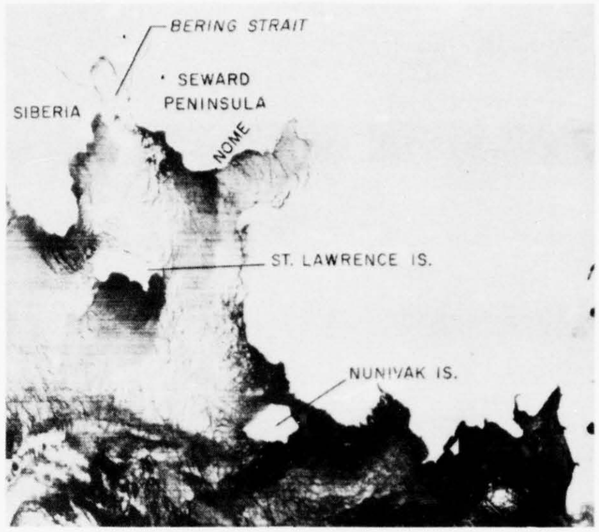


Figure 57. Satellite photograph of ice conditions south of Bering Strait on 2 January 1975 (NOAA-4).

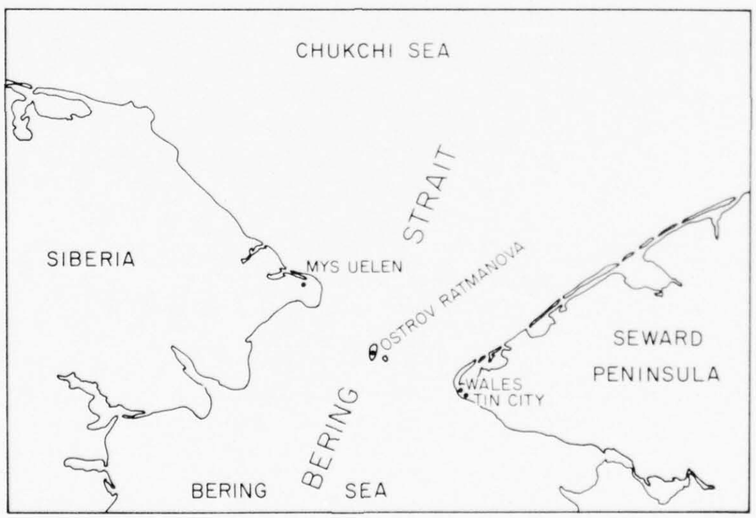


Figure 58. Location of weather stations in the vicinity of the Bering Strait.

The floe movement south of Bering Strait in March reported by Shapiro and Burns[17] (Figure 54) shows southerly movement through the strait. A swath of moving ice can be seen all the way to Pt. Lay, and there are some loose floes that move southward from the first picture to the second. A northerly wind existed at the time, but it is not likely that it could cause such a concentrated movement along the coast; therefore, a southwesterly current is indicated. Shapiro and Burns state that a south-setting current probably existed at the time of the photographs.

F. Atmospheric Pressure Records

Mountain[3,7] has shown a good correlation between the current in the Barrow Canyon and the atmospheric pressure difference between Nome and Barrow for the period from May to August 1973. Higher pressures at Barrow coincide with a southwesterly current. During July and August, when the intrusion was at its peak, the current was always northeasterly, but with reductions in flow corresponding to higher pressures at Barrow.

Figure 59 is a plot of 30-year averages of the pressure difference for each month. The excess pressure at Barrow is lowest in July and August. Mountain's plot of current and pressure difference shows that an excess pressure of about 10 millibars at Barrow corresponds to a southwesterly flow of about 30 cm s^{-1} in the Barrow Canyon. Figure 59 shows an average excess at Barrow of over 7 millibars from November through May; therefore, southwesterly currents would be expected quite often during these months.

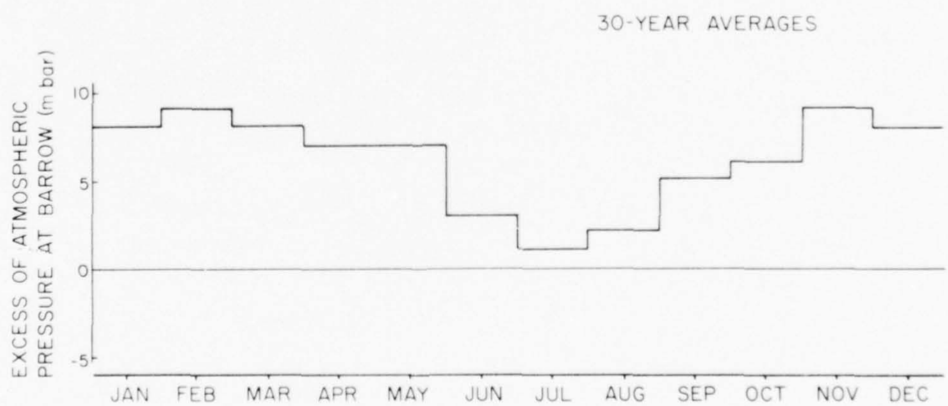


Figure 59. Monthly 30-year averages of the atmospheric pressure excess at Barrow with respect to the pressure at Nome.

X. CONCLUSIONS

Oceanographic measurements along the northwest coast of Alaska have revealed the Alaskan Coastal Current as a narrow stream concentrated along the coast, continuous from the Bering Strait to the Beaufort Sea, with the Barrow Canyon included in its path. In the summer, it runs northeasterly and carries relatively warm water from the Bering Sea along the coast and eventually into the Beaufort Sea, where it dissolves into large eddies. At other times of the year, its flow is greatly diminished and often reversed, yet still confined to a narrow swath close to the coast. The water carried by the current is often of a different density than adjacent coastal waters at the same depth.

Measurements in the spring near Pt. Barrow using a lightweight CTD designed for use from small aircraft at rest on an ice floe have shown some unusual winter activity. A flow of cold, high-density water, which probably results from the increase in salinity caused by freezing at the surface in the shallow water of the Chukchi Sea, was observed in the Barrow Canyon and up to 150 km eastward in the adjacent Beaufort Sea.

An opposing phenomenon is the uprising of higher salinity, higher temperature Atlantic water into the Barrow Canyon from the depths of the Beaufort Sea. Variations and reversals in the coastal current cause partial mixing of these two water masses, producing thermal microstructure of varying types and magnitudes.

1975 was an unusual year resulting in the absence of an ice-free passage along the coast until September. This greatly reduced the coastal current which usually carries large quantities of warm water into the Beaufort Sea. Summer measurements show that the blocked intrusion was forced to greater depths and to the north in the vicinity of Pt. Hope.

In November, as a result of this blockage, there was very little evidence of a warm intrusion in the area northeast of Pt. Barrow and the surface had cooled to a depth of 40 m.

ACKNOWLEDGMENTS

All of our studies were sponsored by the Arctic Submarine Laboratory, Naval Undersea Center, San Diego. Dr. M. Allan Beal served as Chief Scientist during the icebreaker cruises provided by the U.S. Coast Guard and, in addition, provided valuable consultation during the preparation of this report. The cooperation from Dr. R.G. Paquette and Dr. R.H. Bourke of the Naval Postgraduate School during the cruise from Nome to Wainwright was greatly appreciated. Field support for the ice-floe camps, and aircraft for the spring surveys, were provided by the Naval Arctic Research Laboratory through funding by the Office of Naval Research.

The field work and data processing performed by APL staff members Peter Becker and Tim Wen were a major contribution to this report.

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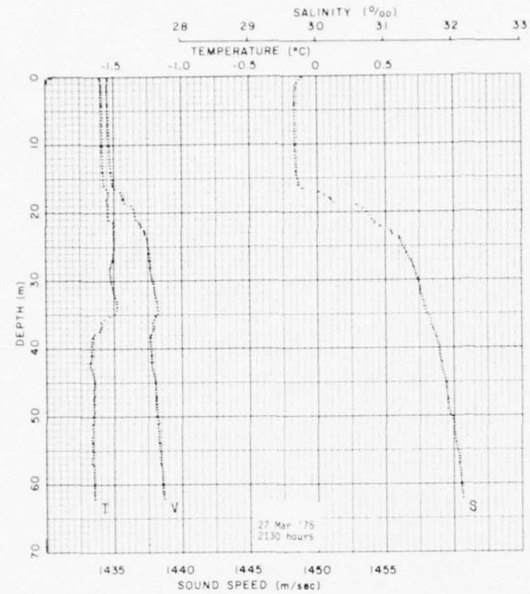
APPENDIX A

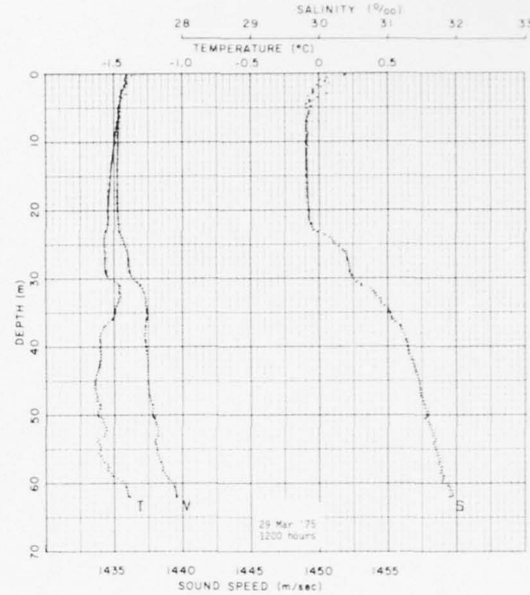
SPRING 1975 ICE CAMP MEASUREMENTS

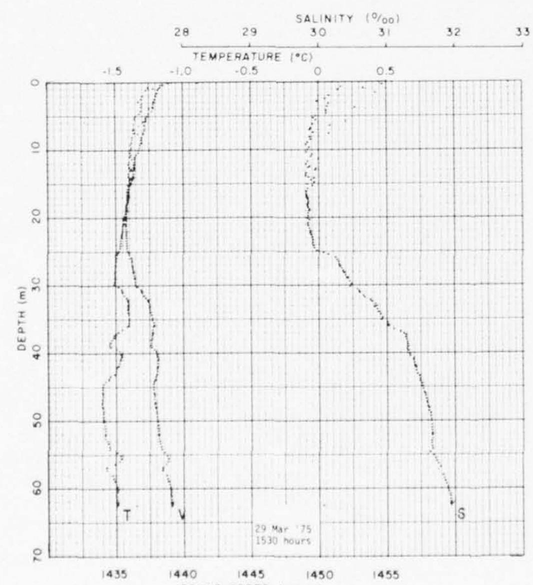
The oceanographic measurements from a drifting ice floe (7 March to 8 April) are presented here. Data on currents, along with some remarks on the data, begin on page A14.

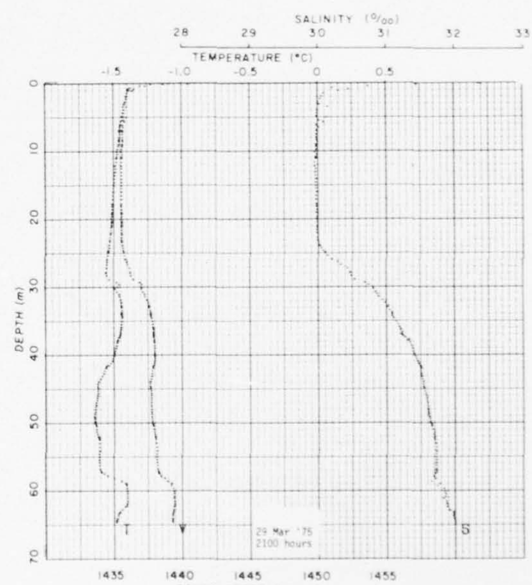
Date	Time	Wind Speed (kn)	Wind Direction (° Magnetic)	Air Temp. (°F)
Mar 27	2130	25-35	140	
29	1200			
	1530			
	2100			
30	0900	15-20	060	-13
	1200			
	1630			
	2020			
	2355			
31	0845	10-20	045	- 8
	1430			
	1545			
	2130			
Apr 1	0820	5		-18
	1310			
	1845	2-5	N	-18
	2355	0		-25
2	0845	Light	N	-20
	1210			
	1630			
	2015			
3	0015	0		-25
	1000	7-8	045	-25
	1145			
	2135			
4	0015	15-20	E	
	0800	20	070	-13
	1045			
	1200	25-30	060	- 4
	2045			
	2050			

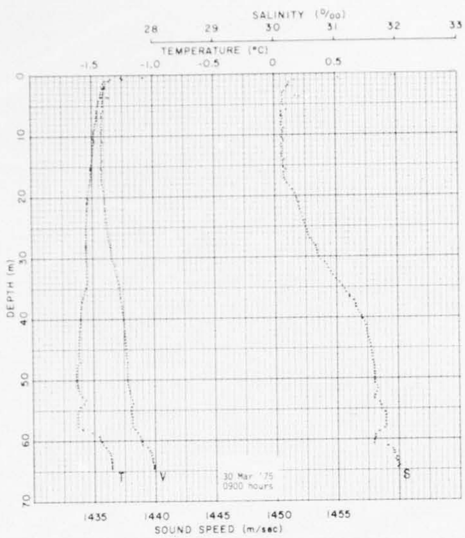
Date	Time	Wind Speed (kn)	Wind Direction (°Magnetic)	Air Temp. (°F)
Apr 5	0015	5-10	060	-18
	0845	7-10	060	-14
	1300			
	1600	7-10		-10
	2000	5-10	060	-14
	2400	0-5		-18
6	0800	5-7	050	-18
	1200	10-15	035	-12
	1600	8-10	035	-10
	2000	5	035	-12
7	0030	10	030	-12
	0830	5	005	-20
	1200	10	005	-18
	1600	10	000	-14
	2200	5-10	005	-20
8	0100	0		-18
	0800	7	325	-18
	1200	7-10	325	-16

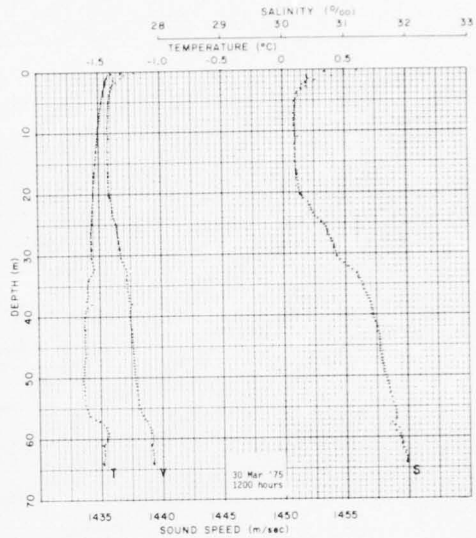

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
T
V
S
27 Mar '75
2130 hours

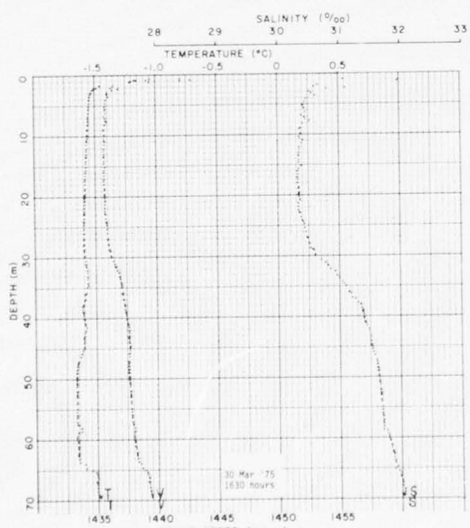

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
T
V
S
29 Mar '75
1200 hours

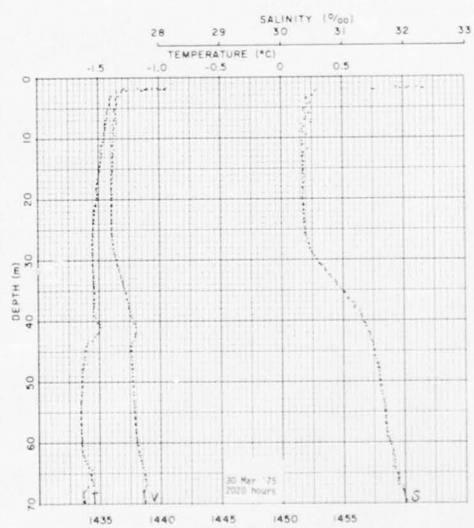

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
T
V
S
29 Mar '75
1530 hours

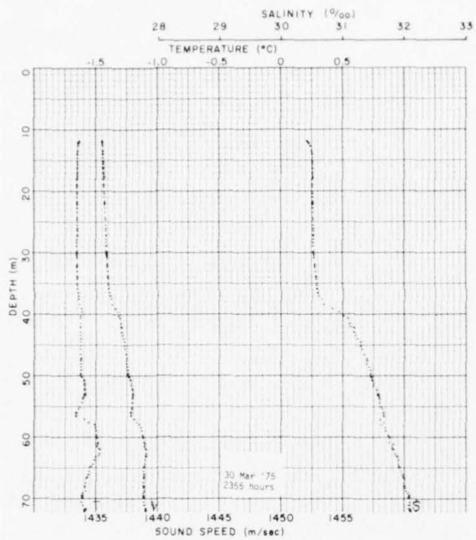

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
T
V
S
29 Mar '75
2100 hours

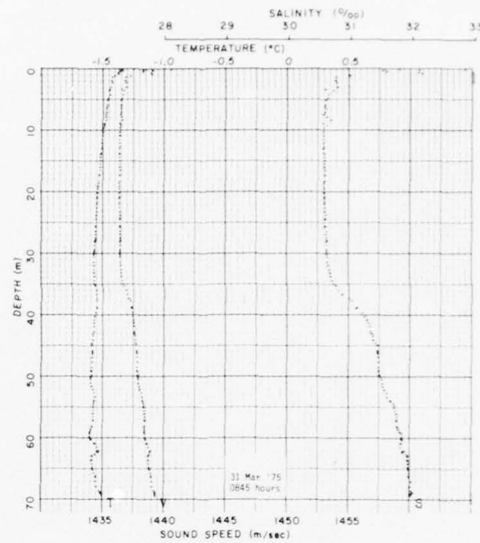

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
30 Mar '75
0900 hours

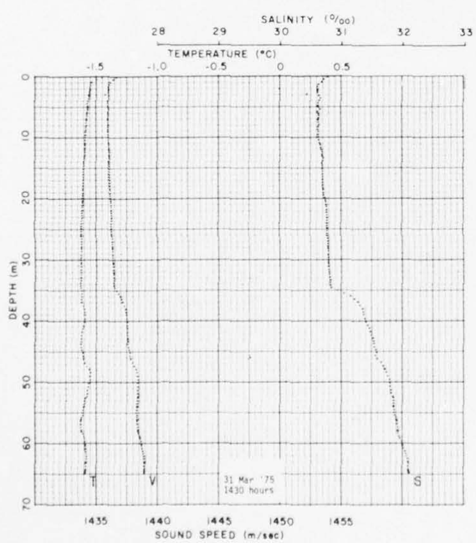

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
30 Mar '75
1200 hours

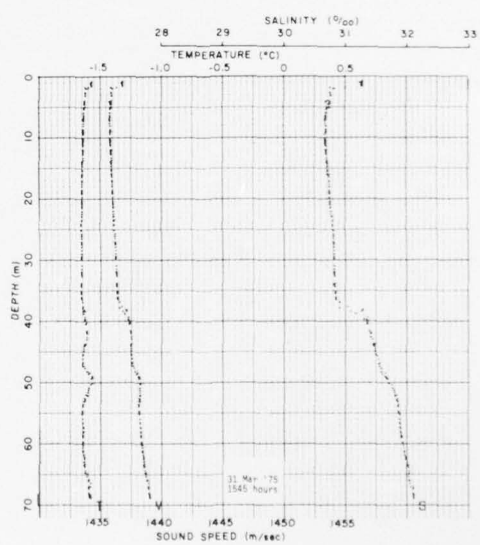

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
30 Mar '75
1630 hours

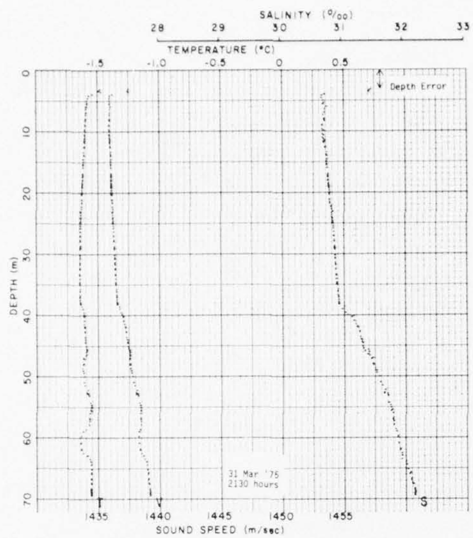

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
30 Mar '75
2020 hours

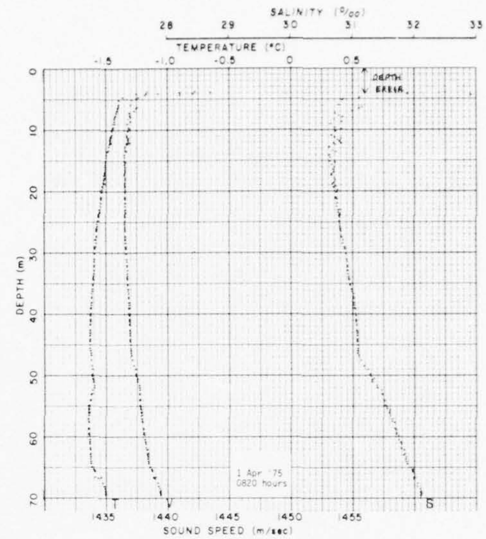

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
30 Mar '75
2355 hours
T V S
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

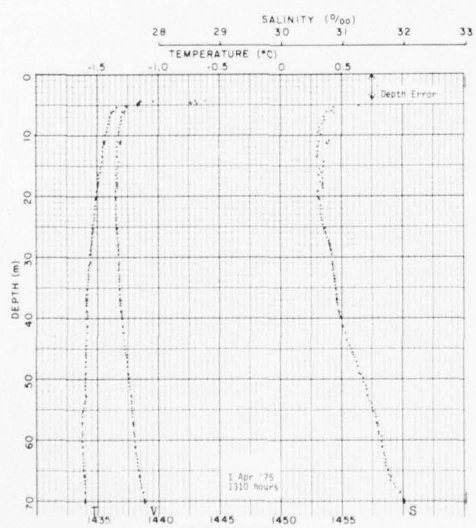

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
31 Mar '75
0845 hours
T V S
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

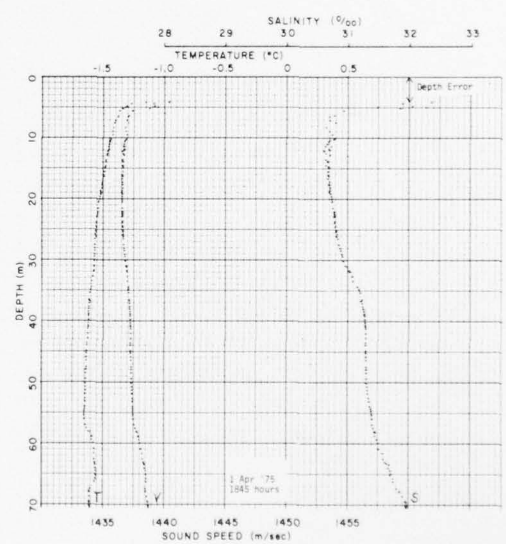

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
31 Mar '75
1430 hours
T V S
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

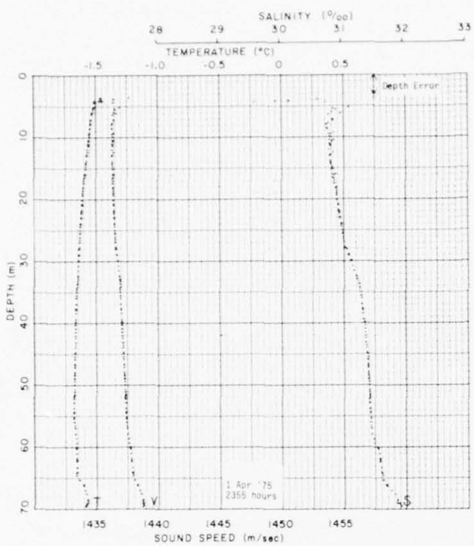

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
31 Mar '75
1545 hours
T V S
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

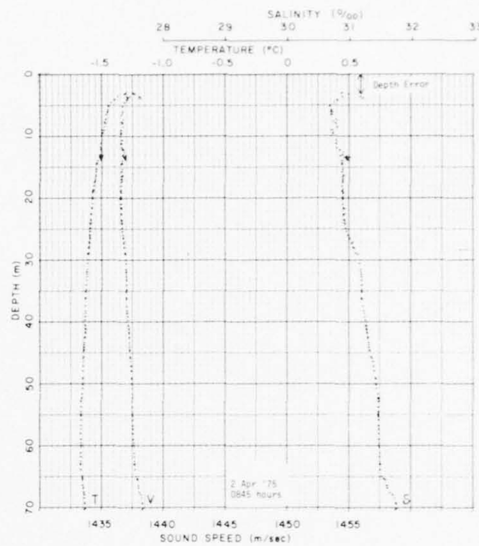

SALINITY (°/oo)
TEMPERATURE (°C)
Depth Error
DEPTH (m)
31 Mar '75
2130 hours
SOUND SPEED (m/sec)

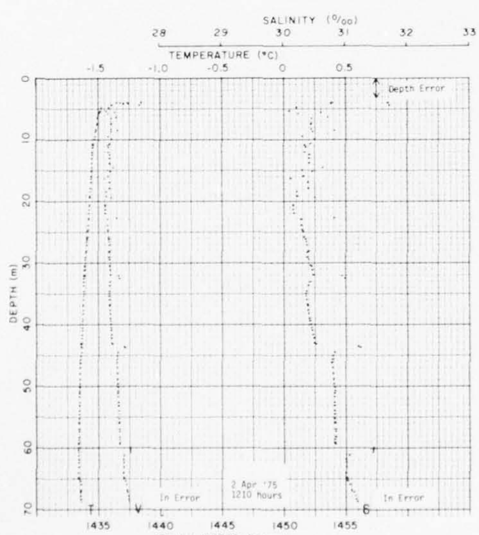

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH ERROR
DEPTH (m)
1 Apr '75
0820 hours
SOUND SPEED (m/sec)

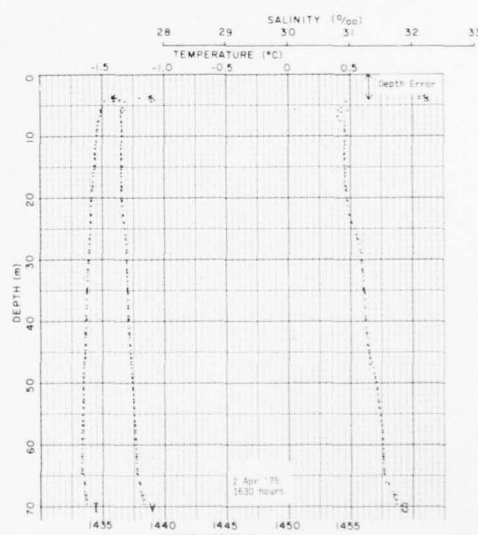

SALINITY (°/oo)
TEMPERATURE (°C)
Depth Error
DEPTH (m)
1 Apr '75
1310 hours
SOUND SPEED (m/sec)

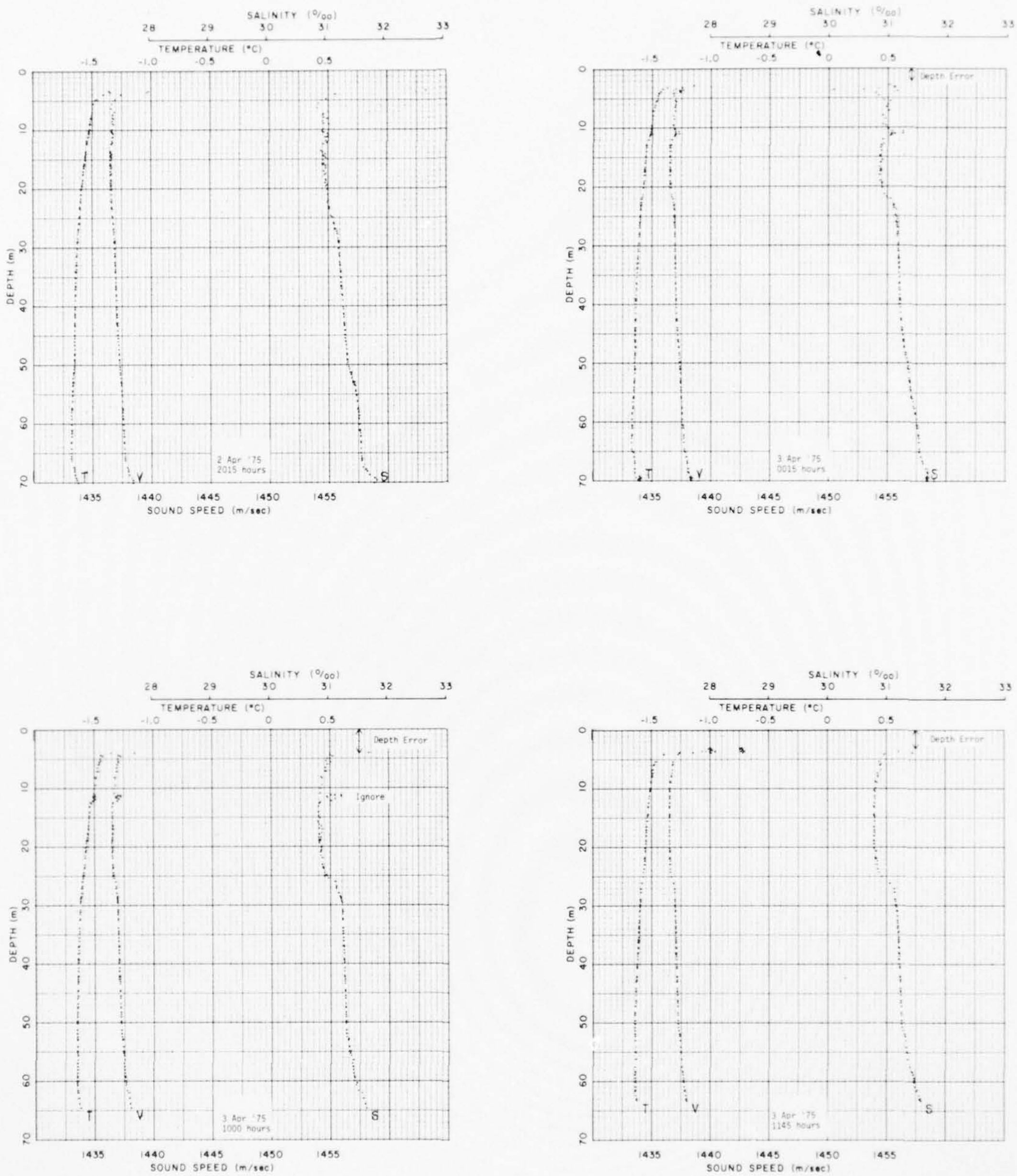

SALINITY (°/oo)
TEMPERATURE (°C)
Depth Error
DEPTH (m)
1 Apr '75
1845 hours
SOUND SPEED (m/sec)

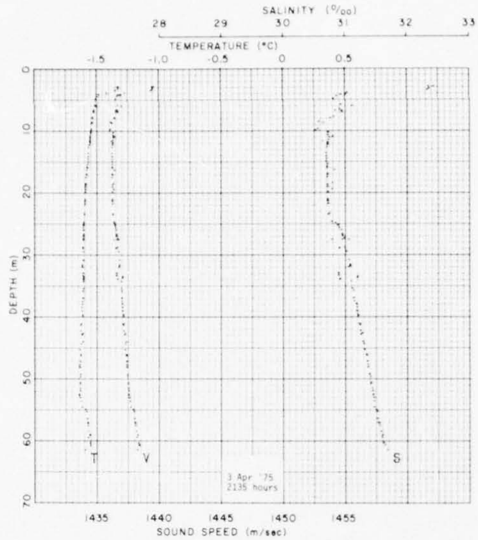

SALINITY (°/oo)
TEMPERATURE (°C)
Depth Error
DEPTH (m)
1 Apr '75
2355 hours
SOUND SPEED (m/sec)

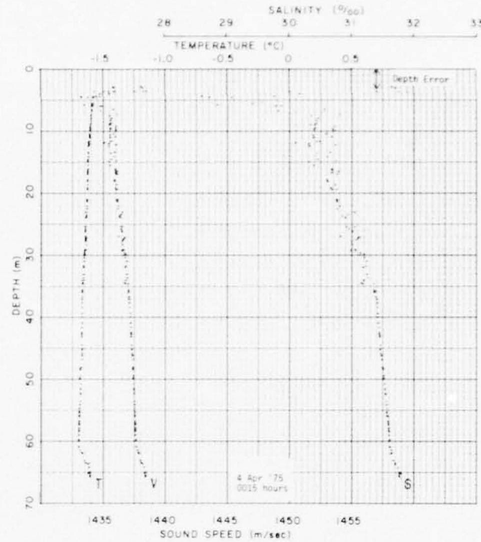

SALINITY (°/oo)
TEMPERATURE (°C)
Depth Error
DEPTH (m)
2 Apr '75
0845 hours
SOUND SPEED (m/sec)

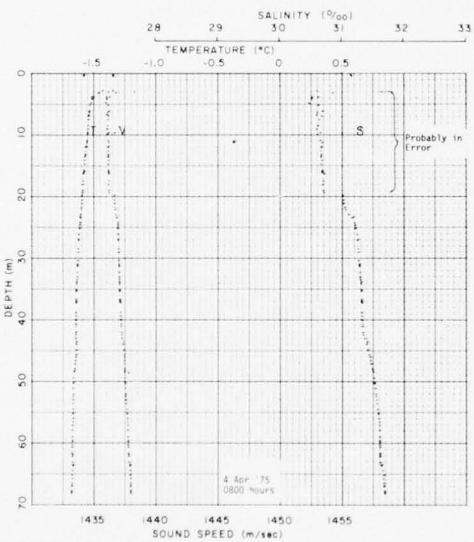

SALINITY (°/oo)
TEMPERATURE (°C)
Depth Error
DEPTH (m)
In Error
2 Apr '75
1210 hours
In Error
SOUND SPEED (m/sec)

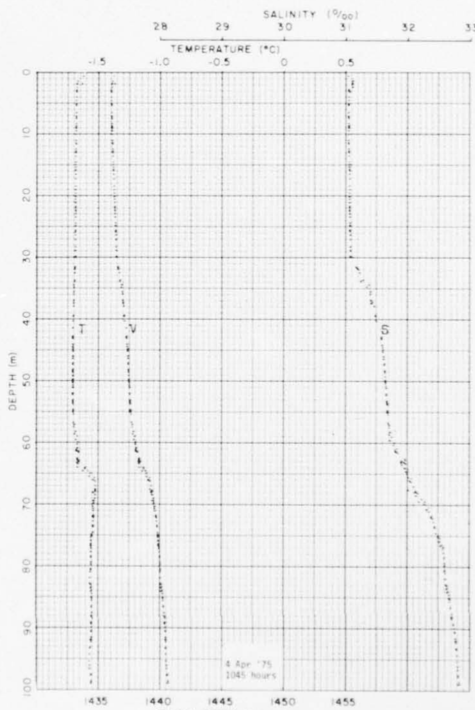

SALINITY (°/oo)
TEMPERATURE (°C)
Depth Error
DEPTH (m)
2 Apr '75
1630 hours
SOUND SPEED (m/sec)

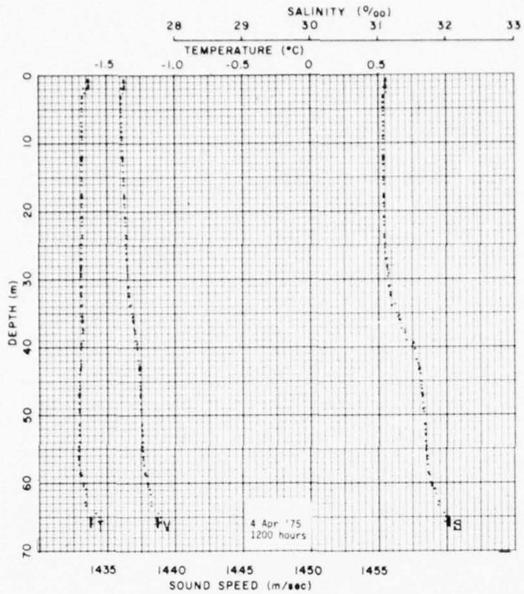

SALINITY (0/00)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
2 Apr '75
2015 hours
3 Apr '75
0015 hours
Depth Error
3 Apr '75
1000 hours
Ignore
3 Apr '75
1145 hours
T
V
S

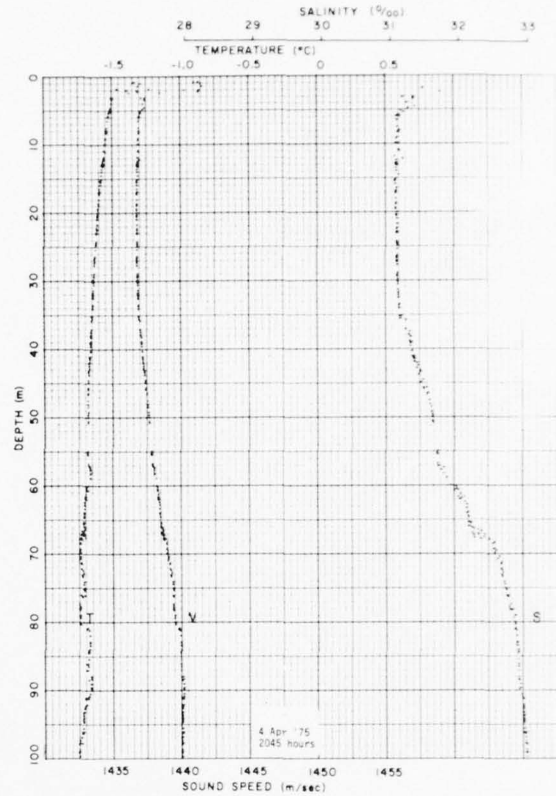

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
T
V
S
3 Apr '75
2135 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

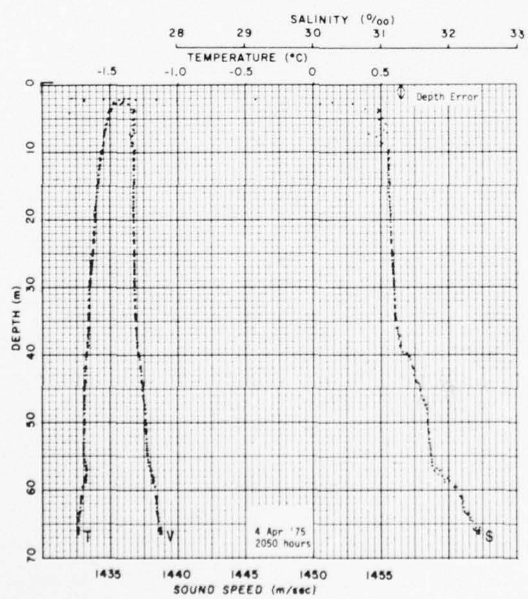

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
Depth Error
DEPTH (m)
0 10 20 30 40 50 60 70
T
V
S
4 Apr '75
0015 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

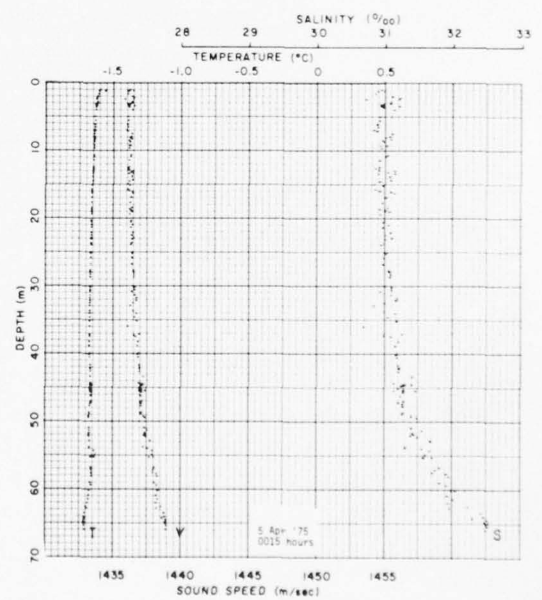

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
Probably in Error
DEPTH (m)
0 10 20 30 40 50 60 70
T
V
S
4 Apr '75
0800 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

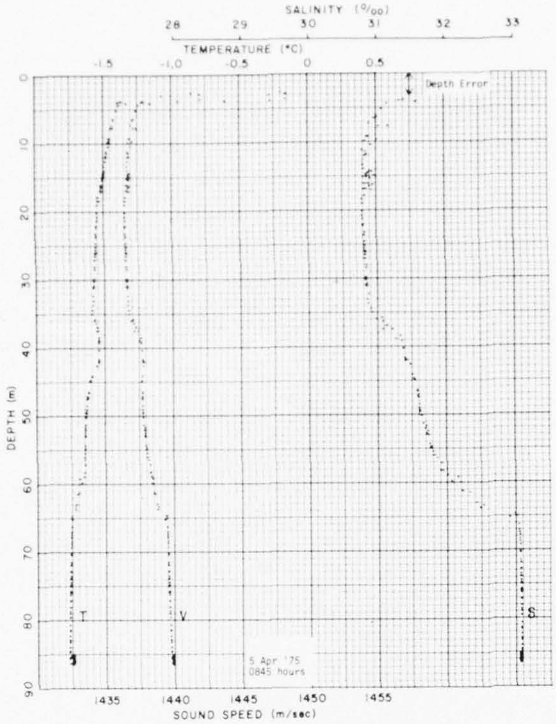

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70 80 90 100
T
V
S
4 Apr '75
1045 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

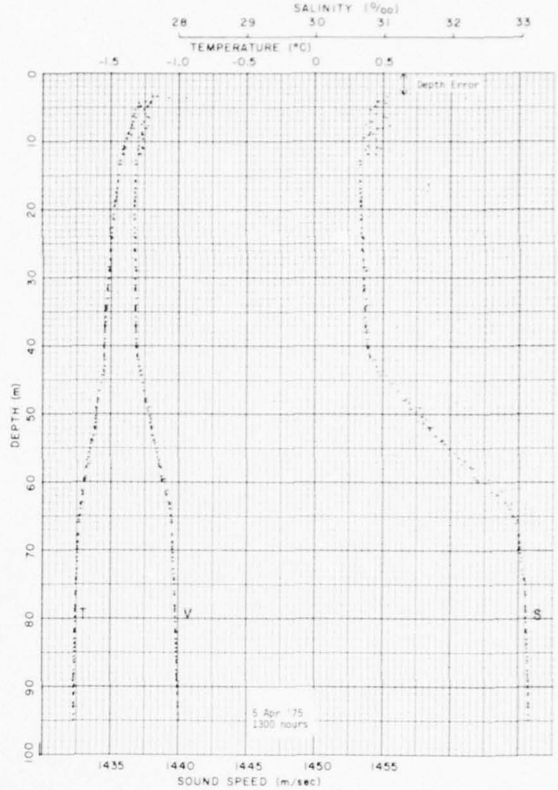

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
4 Apr '75
1200 hours
T
V
S

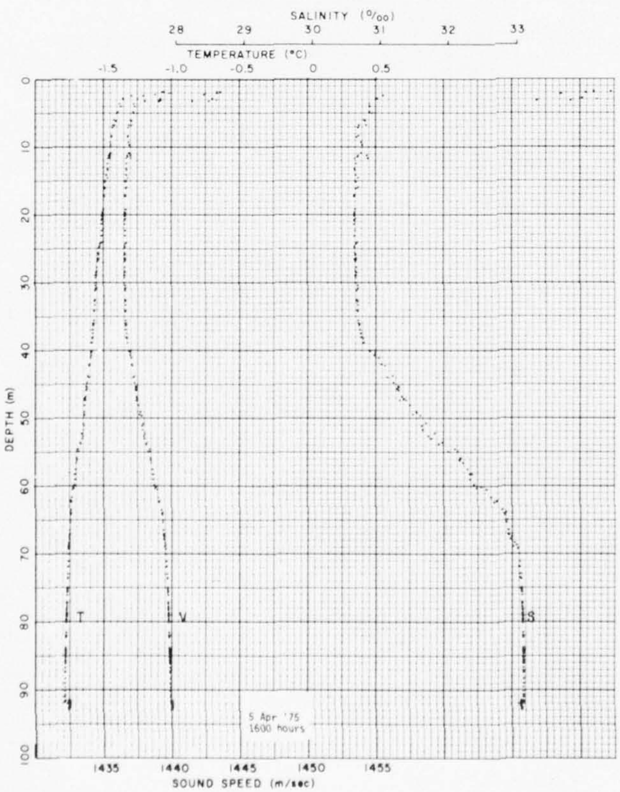

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
4 Apr '75
2045 hours
T
V
S

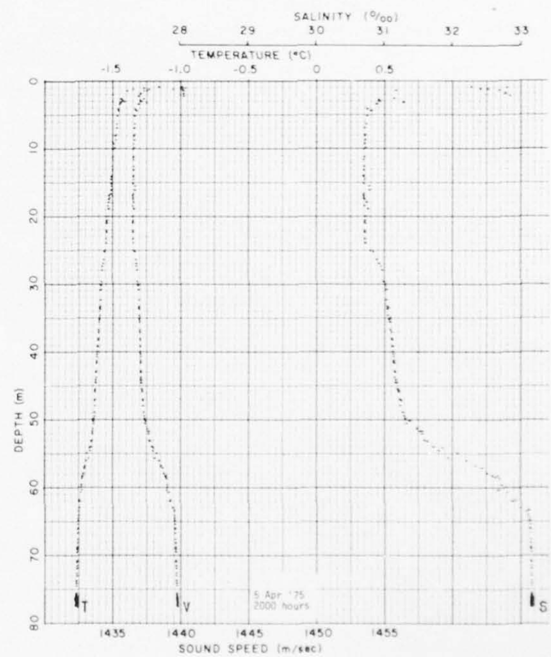

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
Depth Error
4 Apr '75
2050 hours
T
V
S

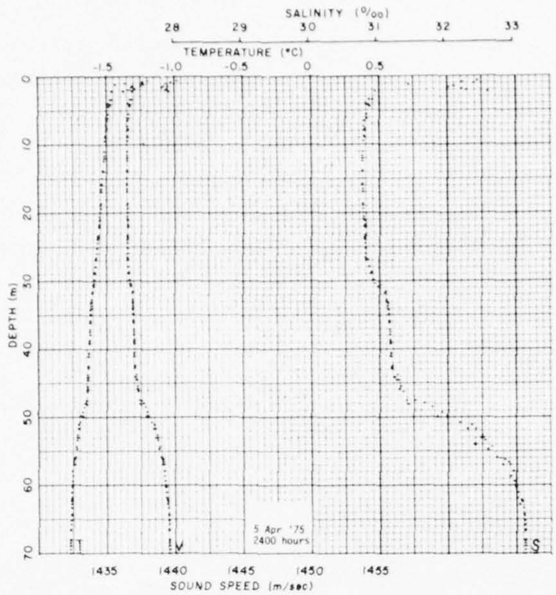

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
SOUND SPEED (m/sec)
5 Apr '75
0015 hours
T
V
S

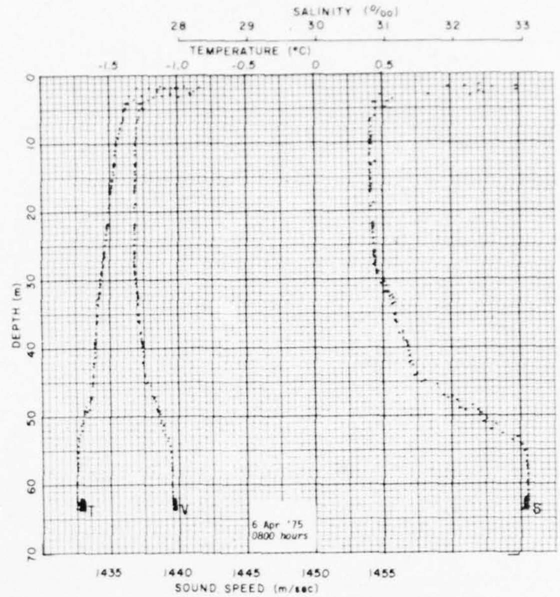

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
Depth Error
DEPTH (m)
T
V
S
5 Apr '75
0845 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

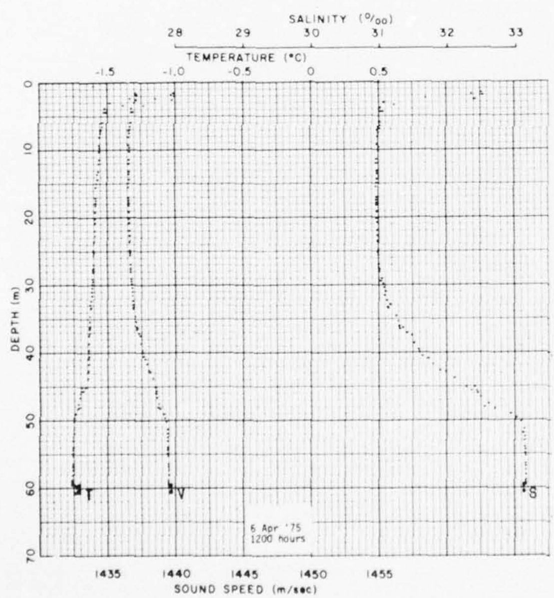

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
Depth Error
DEPTH (m)
T
V
S
5 Apr '75
1300 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

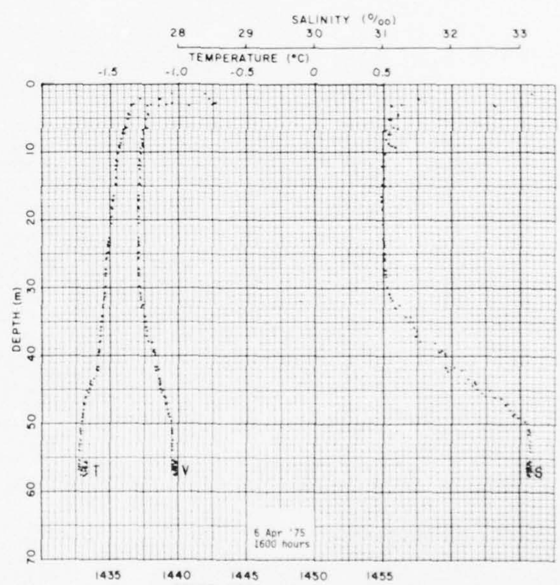

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
T
V
S
5 Apr '75
1600 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

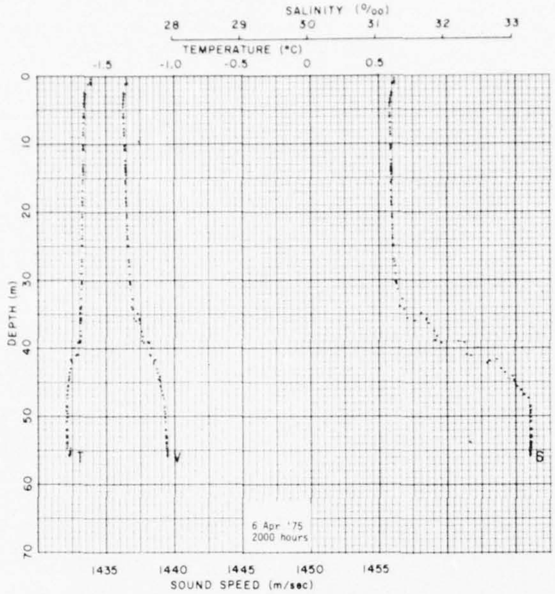

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
T
V
S
5 Apr '75
2000 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

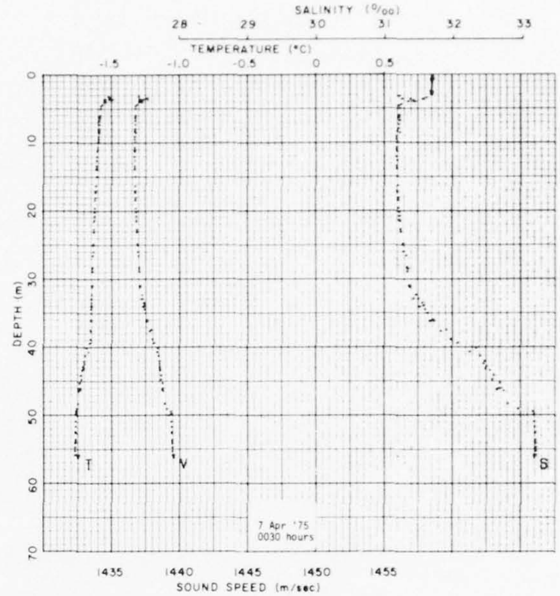

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
T V S
5 Apr '75
2400 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

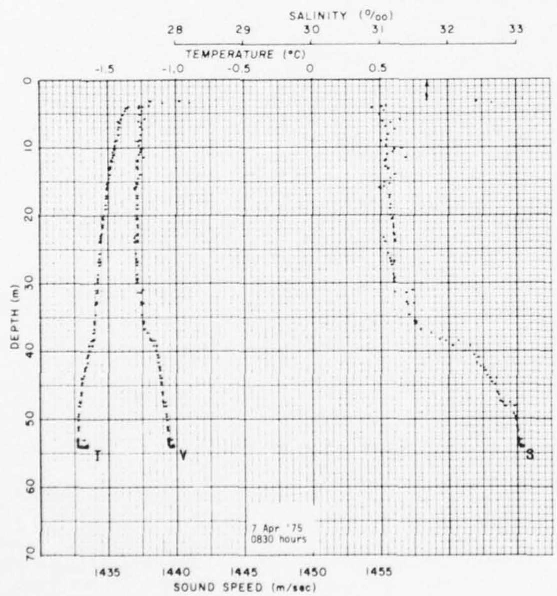

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
T V S
6 Apr '75
0800 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

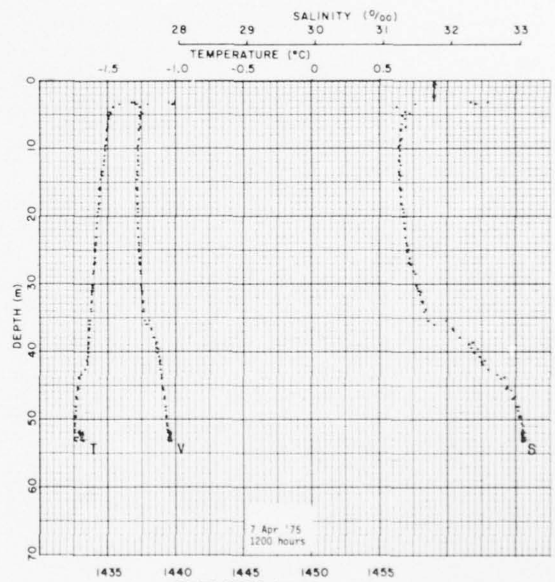

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
T V S
6 Apr '75
1200 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

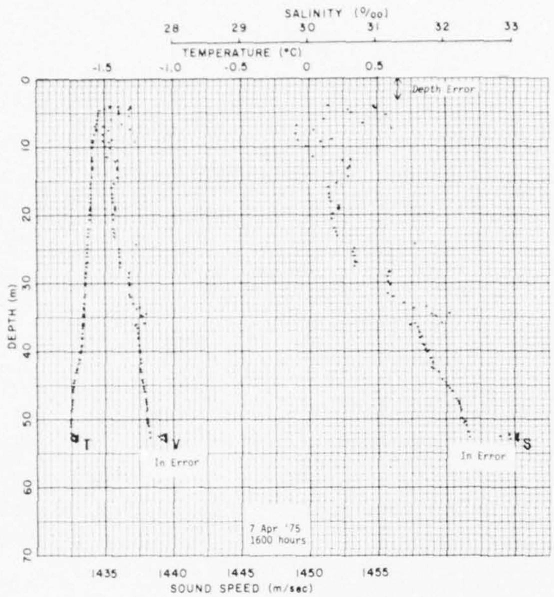

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
T V S
6 Apr '75
1600 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

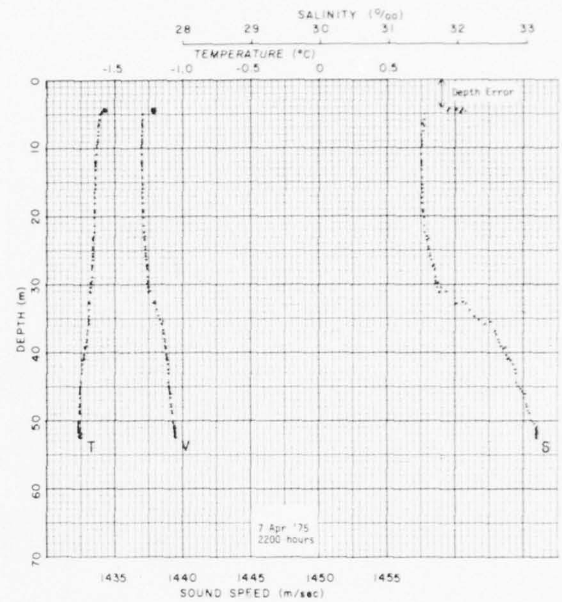

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
T
V
S
6 Apr '75
2000 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

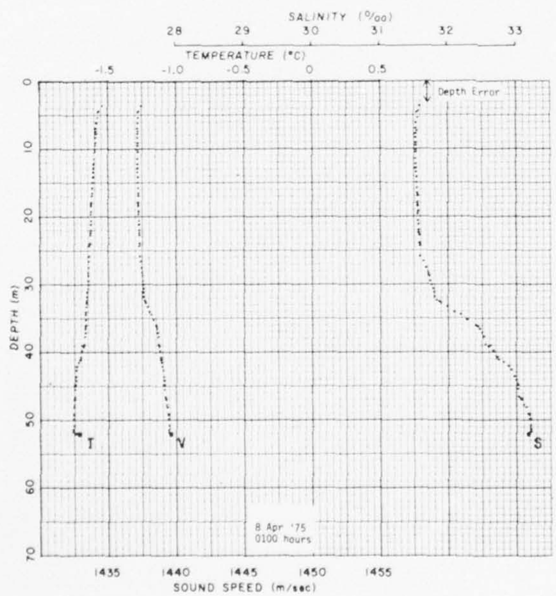

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
T
V
S
7 Apr '75
0030 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

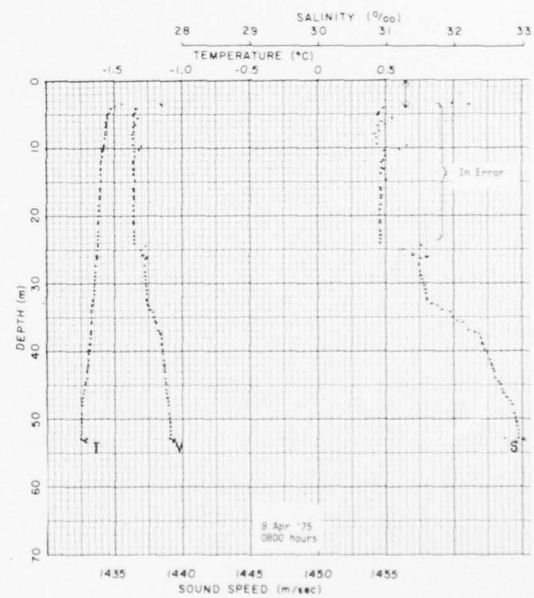

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
T
V
S
7 Apr '75
0830 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

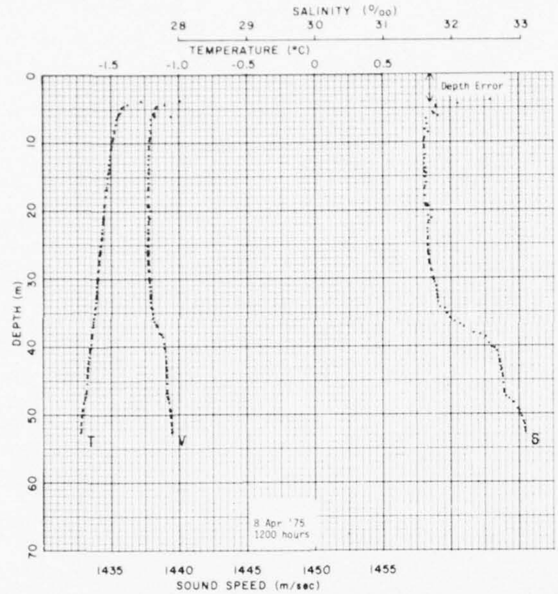

SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 10 20 30 40 50 60 70
T
V
S
7 Apr '75
1200 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)


SALINITY (°/oo)
TEMPERATURE (°C)
Depth Error
DEPTH (m)
In Error
In Error
7 Apr '75
1600 hours
SOUND SPEED (m/sec)


SALINITY (°/oo)
TEMPERATURE (°C)
Depth Error
DEPTH (m)
7 Apr '75
2200 hours
SOUND SPEED (m/sec)


SALINITY (°/oo)
TEMPERATURE (°C)
Depth Error
DEPTH (m)
8 Apr '75
0100 hours
SOUND SPEED (m/sec)


SALINITY (°/oo)
TEMPERATURE (°C)
In Error
DEPTH (m)
8 Apr '75
0800 hours
SOUND SPEED (m/sec)


SALINITY (°/oo)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
Depth Error
DEPTH (m)
0 10 20 30 40 50 60 70
T
V
S
8 Apr '75
1200 hours
1435 1440 1445 1450 1455
SOUND SPEED (m/sec)

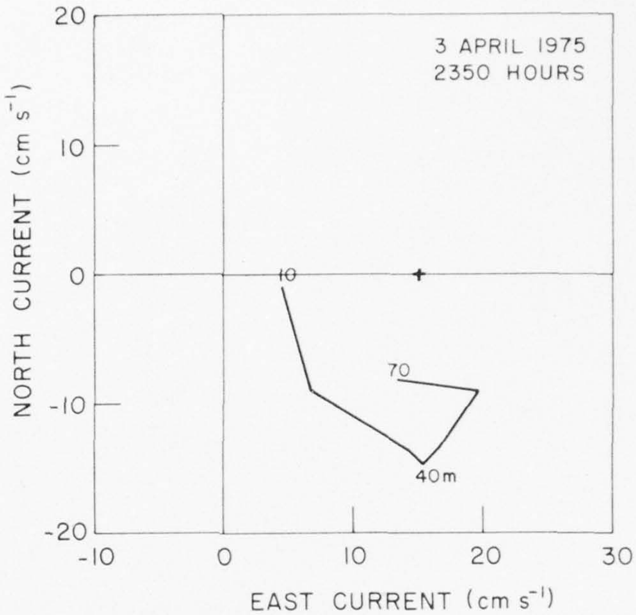
Currents were measured at the ice camp at the following times:

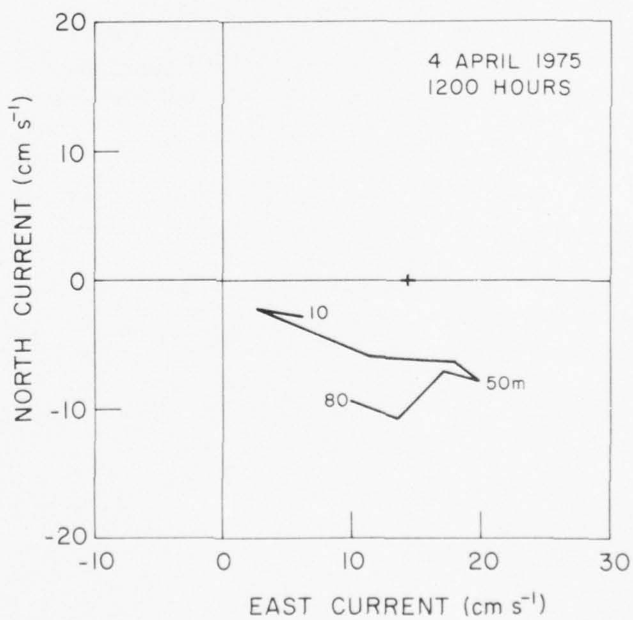
Date	Local Time	Depth (m)
3 April	2350	10-70
4	1200	10-80
4	2330	10-90
5	1200	10-90
5	2300	10-80
6	1130	10-65
6	2230	10-51
7	1300	10-50
8	0300	10-55
8	1200	10-50

The current measurements were made from the drifting ice floe and therefore do not reflect the true currents. The current measured at each depth was plotted on a velocity diagram; i.e., a vector from the origin to each point represents the velocity at that depth relative to the floe. To determine the true current, the drift of the floe must be assumed and designated by a point on the diagram that represents a vector in the opposite direction. Vectors drawn from this point (which represents the relative velocity of stationary water) to the other points represent true currents.

The drift of the floe was taken either from a 4-day average (indicated by a + on the diagram) or from a reading with the current meter just off the bottom (an x on the diagram). Because of the uncertainty as to the floe drift, vectors to the several points have not been drawn.

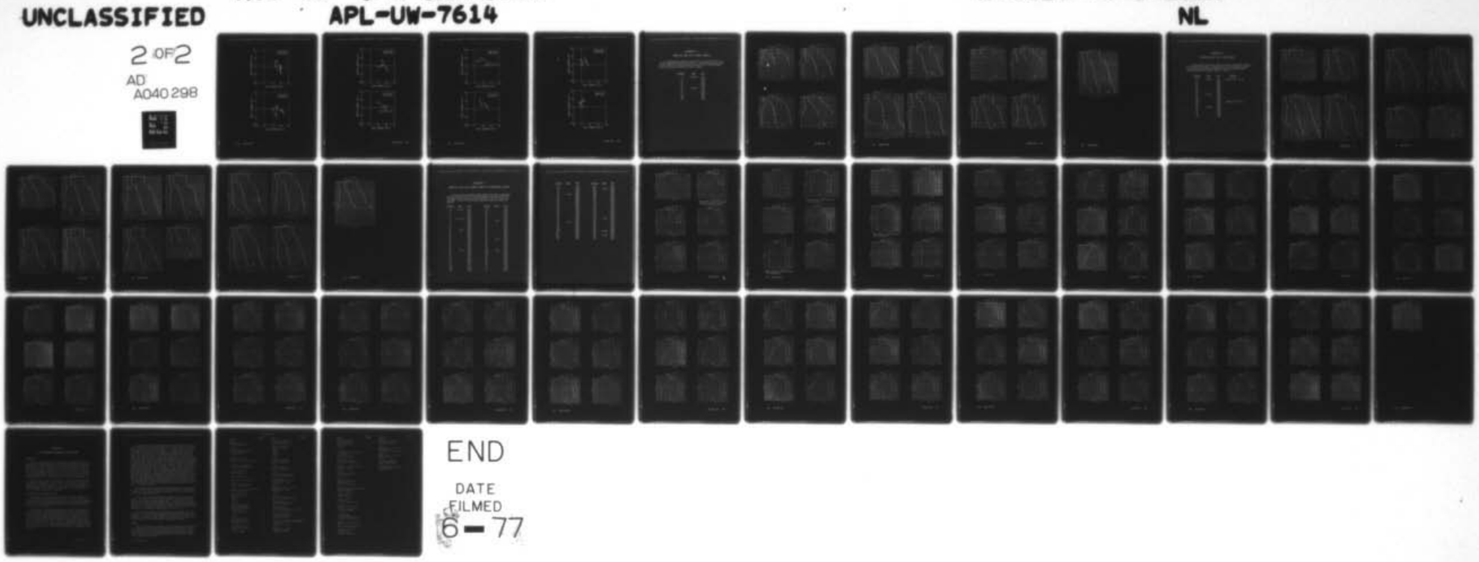
The drift velocity on 8 April was very small and therefore no average is shown. The relative currents are assumed to be true currents.


3 APRIL 1975
2350 HOURS
NORTH CURRENT (cm s^{-1})
EAST CURRENT (cm s^{-1})
10
70
40m
20
10
0
-10
-20
-10
0
10
20
30

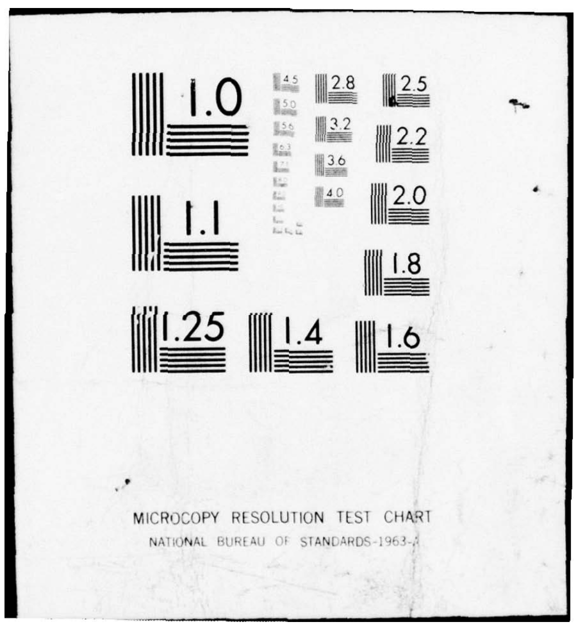

4 APRIL 1975
1200 HOURS
NORTH CURRENT (cm s^{-1})
EAST CURRENT (cm s^{-1})
10
50m
80
20
10
0
-10
-20
-10
0
10
20
30

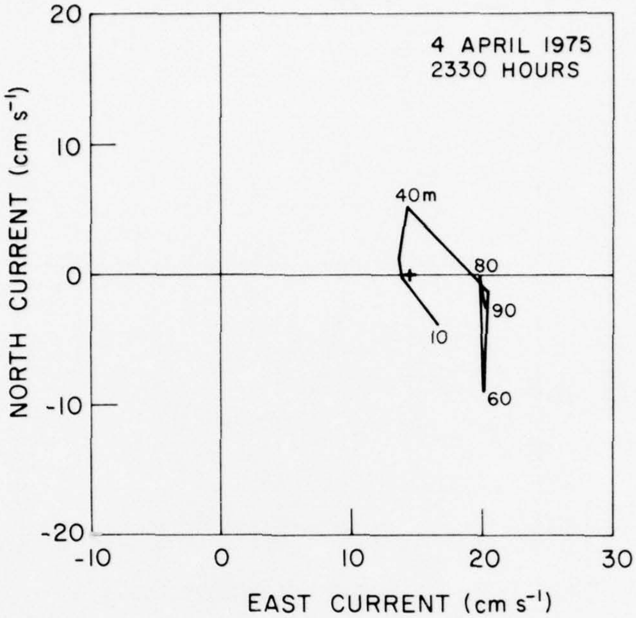
AD-A040 298 WASHINGTON UNIV SEATTLE APPLIED PHYSICS LAB F/G 8/3
CHUKCHI SEA OCEANOGRAPHY: 1975 MEASUREMENTS AND A REVIEW OF COA--ETC(U)
NOV 76 G R GARRISON N00123-74-C-2064
UNCLASSIFIED APL-UW-7614 NL

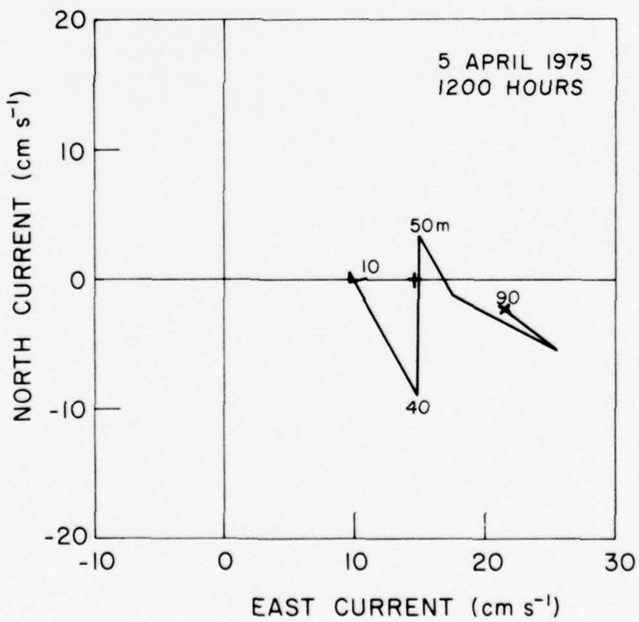
2 OF 2
AD
A040 298

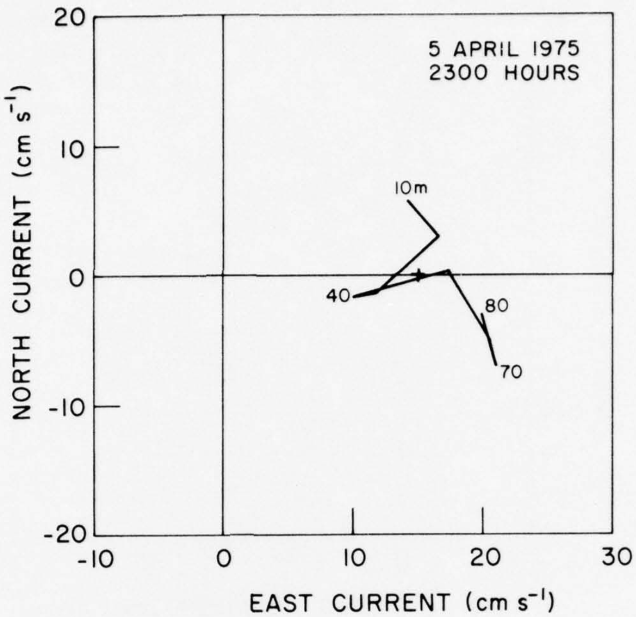


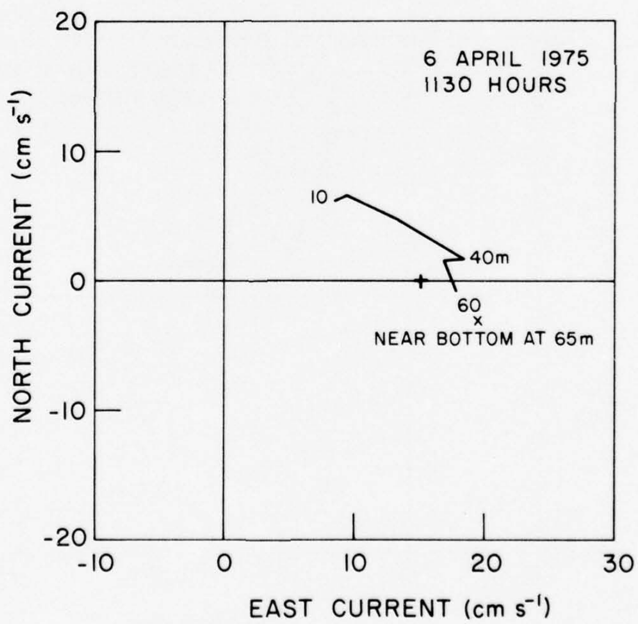
END
DATE
FILMED
6-77

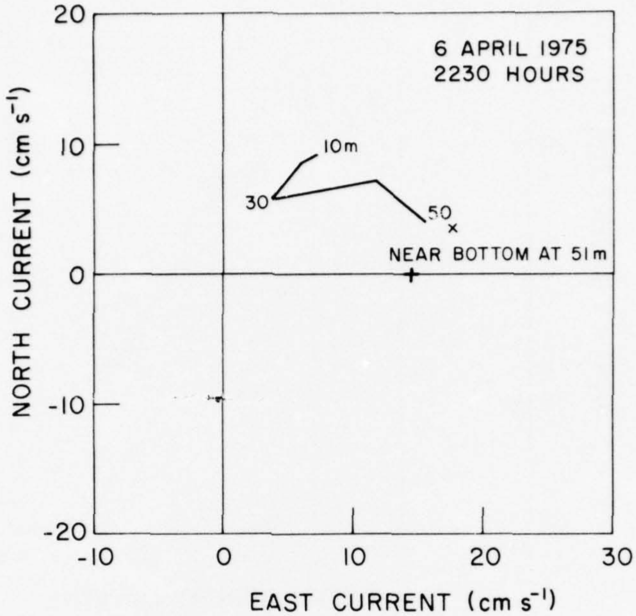

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

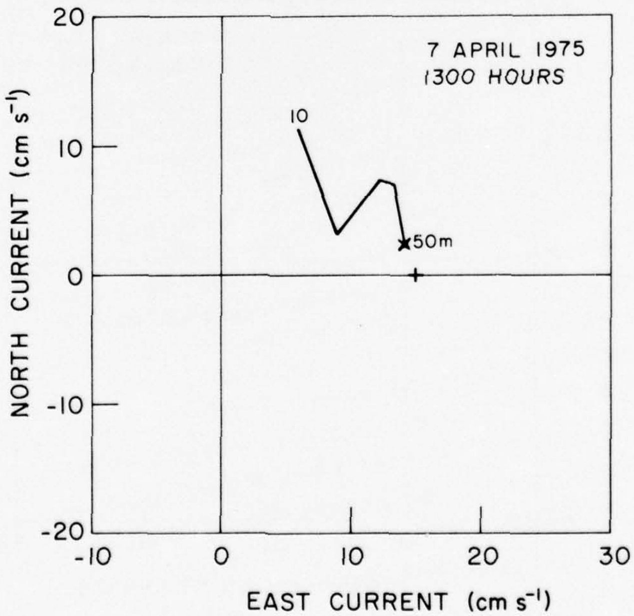

4 APRIL 1975
2330 HOURS
NORTH CURRENT (cm s^{-1})
EAST CURRENT (cm s^{-1})
40m
80
90
10
60

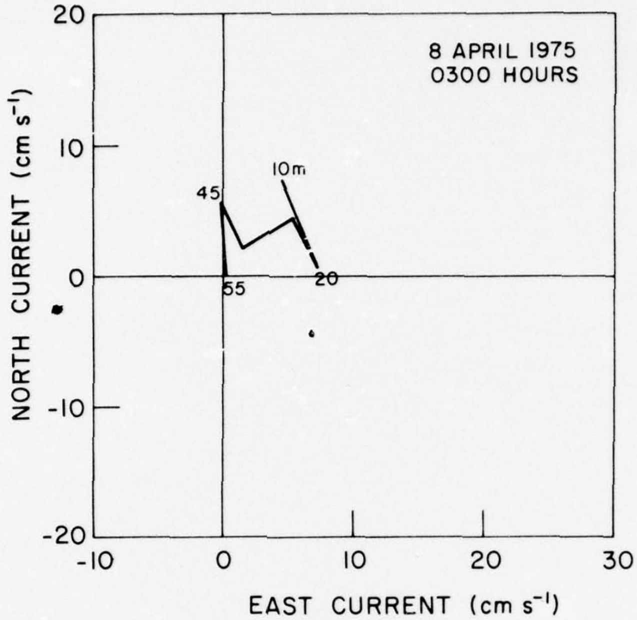

5 APRIL 1975
1200 HOURS
NORTH CURRENT (cm s^{-1})
EAST CURRENT (cm s^{-1})
50m
10
90
40

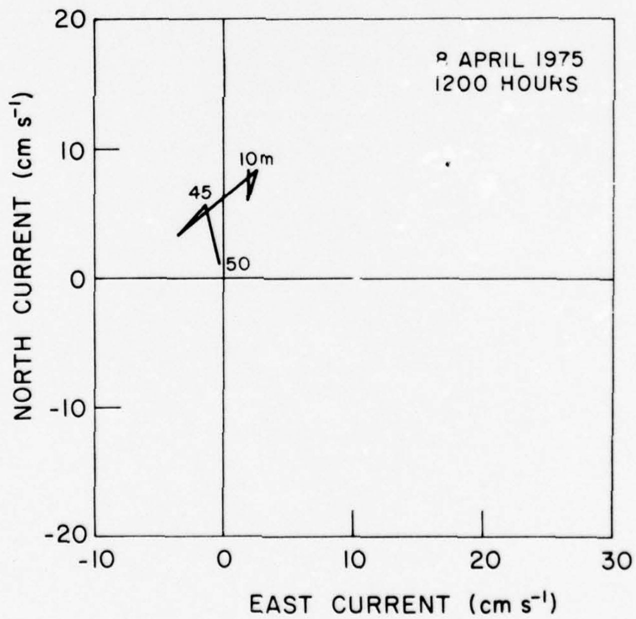

5 APRIL 1975
2300 HOURS
NORTH CURRENT (cm s⁻¹)
EAST CURRENT (cm s⁻¹)
10m
40
80
70
20
10
0
-10
-20
-10
0
10
20
30


6 APRIL 1975
1130 HOURS
NORTH CURRENT (cm s⁻¹)
EAST CURRENT (cm s⁻¹)
10
40m
60
NEAR BOTTOM AT 65m
20
10
0
-10
-20
-10
0
10
20
30


6 APRIL 1975
2230 HOURS
10m
30
50
NEAR BOTTOM AT 51m
NORTH CURRENT (cm s⁻¹)
EAST CURRENT (cm s⁻¹)
20
10
0
-10
-20
-10
0
10
20
30


7 APRIL 1975
1300 HOURS
10
50m
NORTH CURRENT (cm s⁻¹)
EAST CURRENT (cm s⁻¹)
20
10
0
-10
-20
-10
0
10
20
30


8 APRIL 1975
0300 HOURS
NORTH CURRENT (cm s⁻¹)
EAST CURRENT (cm s⁻¹)
10m
45
55
20
20
10
0
-10
-20
-10
0
10
20
30

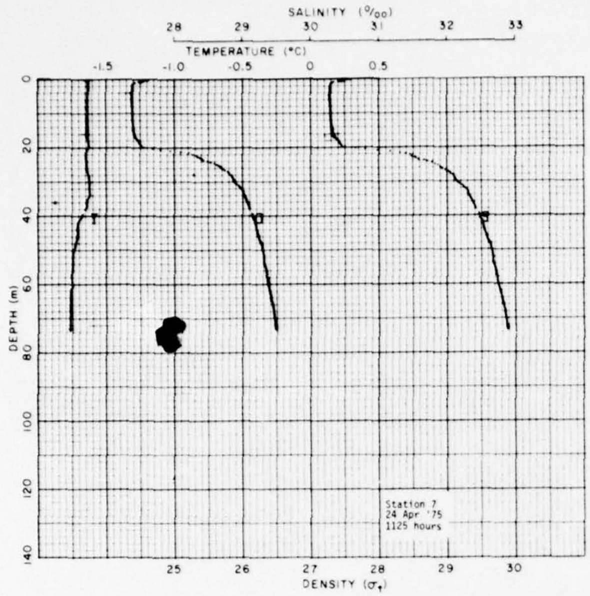

8 APRIL 1975
1200 HOURS
NORTH CURRENT (cm s⁻¹)
EAST CURRENT (cm s⁻¹)
10m
45
50
20
10
0
-10
-20
-10
0
10
20
30

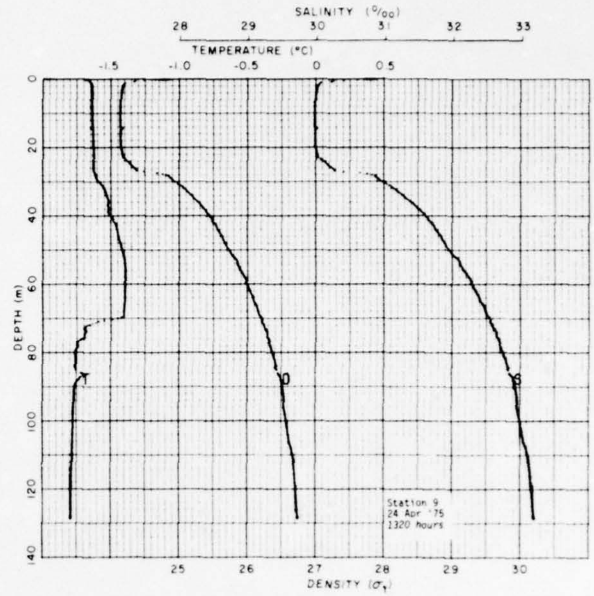
APPENDIX B

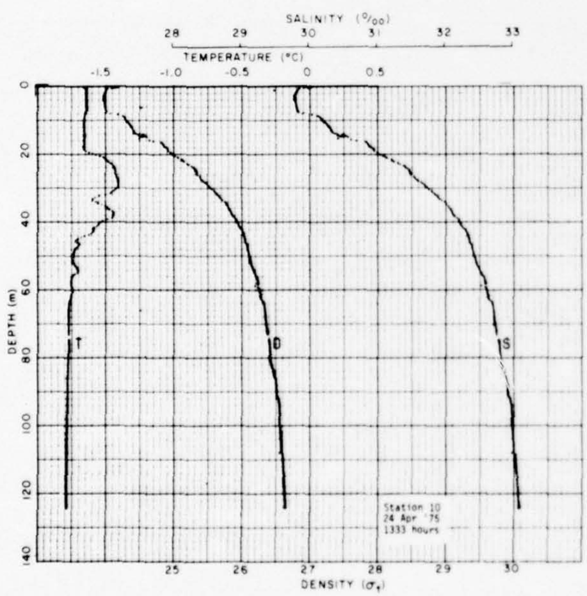
PROFILES FOR 23-27 APRIL SURVEY

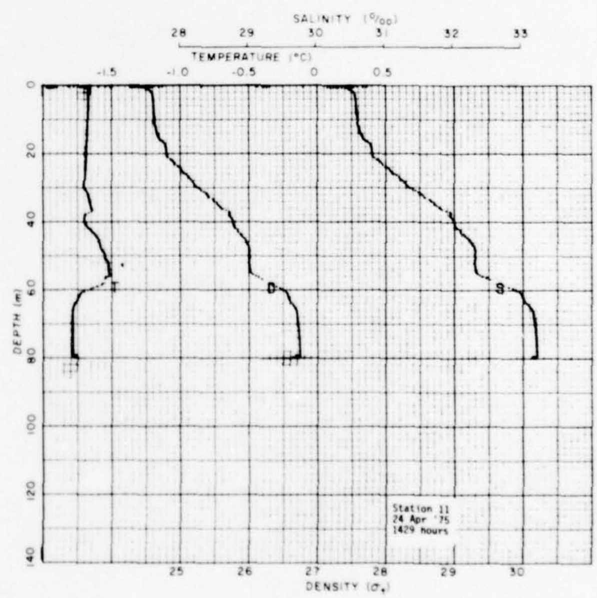
The lightweight profiler was used from a Cessna 180 aircraft to obtain temperature and salinity profiles. The profiles for the survey of 23-27 April are listed here and presented on the following pages. Station locations are shown in Figure 5, page 8.

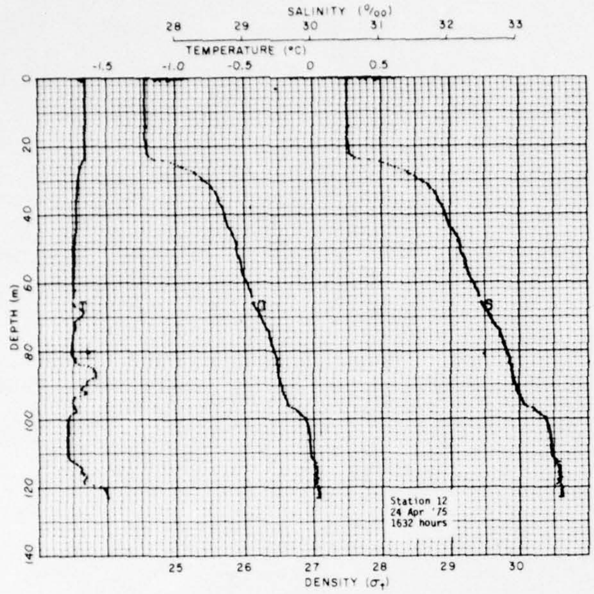
Station	Date	Time
7	24 April	1125
9		1320
10		1333
11		1429
12		1632
13		1740
14	27 April	1141
15		1242
16		1341
17		1439
18		1517
18a		1552
19		1705

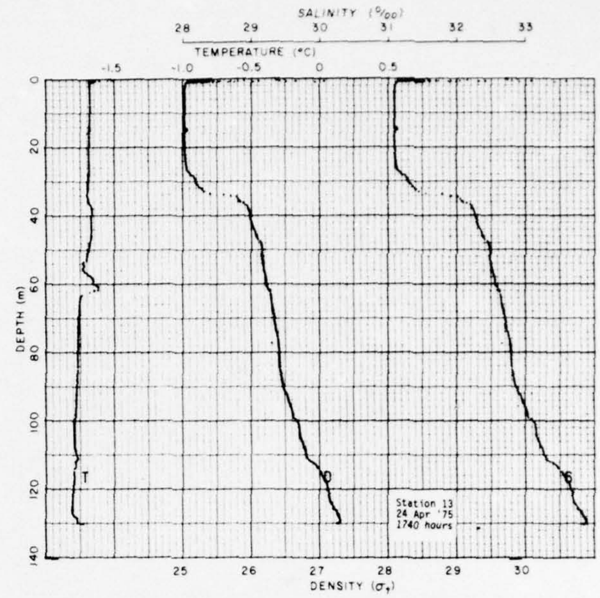

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σt)
Station 7
24 Apr '75
1125 hours

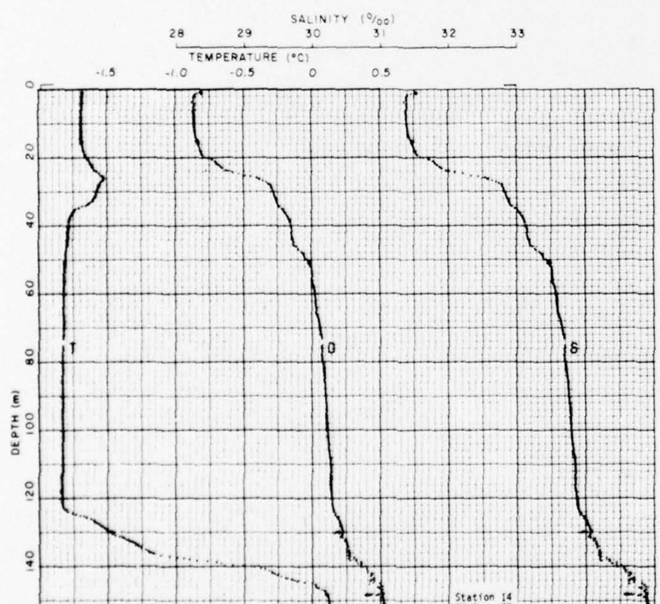

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σt)
Station 9
24 Apr '75
1320 hours


SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σt)
Station 10
24 Apr '75
1333 hours

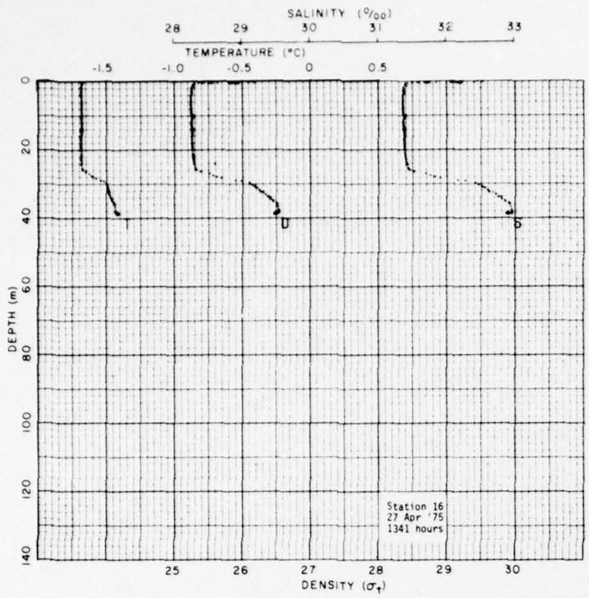

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σt)
Station 11
24 Apr '75
1429 hours

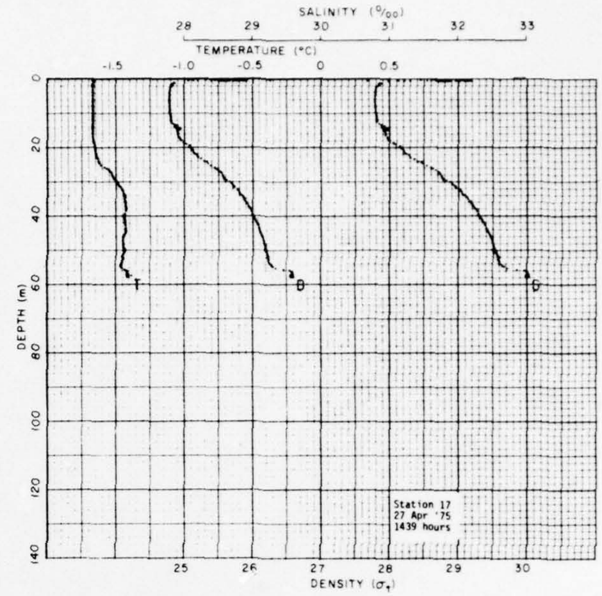

SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
DENSITY (σ_t)
25 26 27 28 29 30
T
D
S
Station 12
24 Apr '75
1632 hours

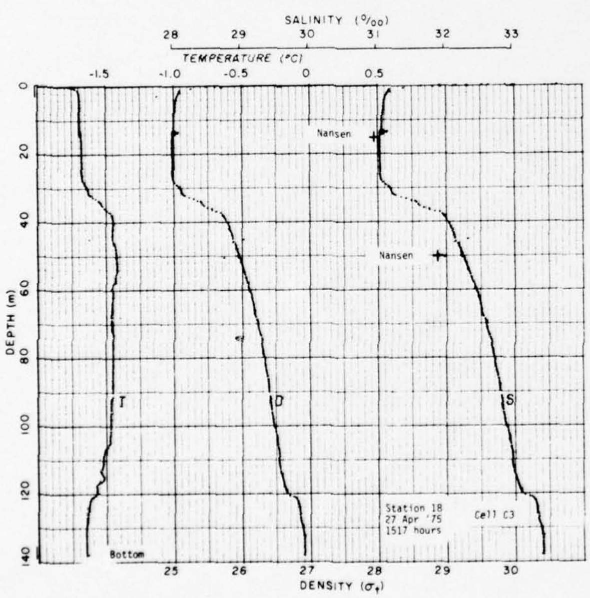

SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
DENSITY (σ_t)
25 26 27 28 29 30
T
D
S
Station 13
24 Apr '75
1740 hours

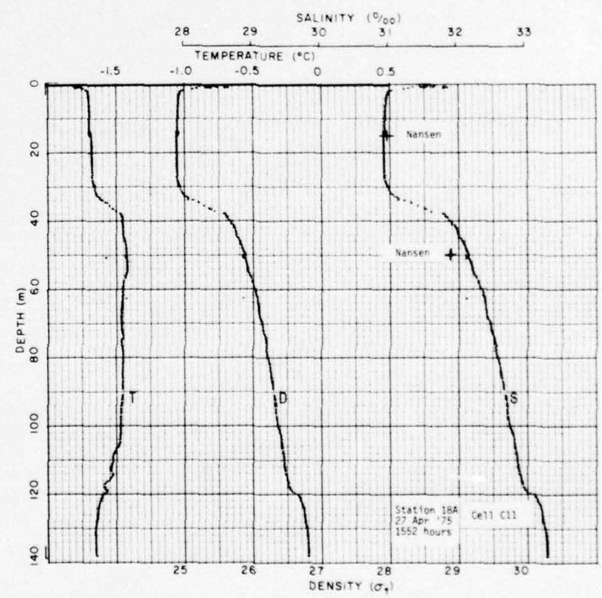

SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
DENSITY (σ_t)
25 26 27 28 29 30
T
D
S
Station 14
27 Apr '75
1141 hours

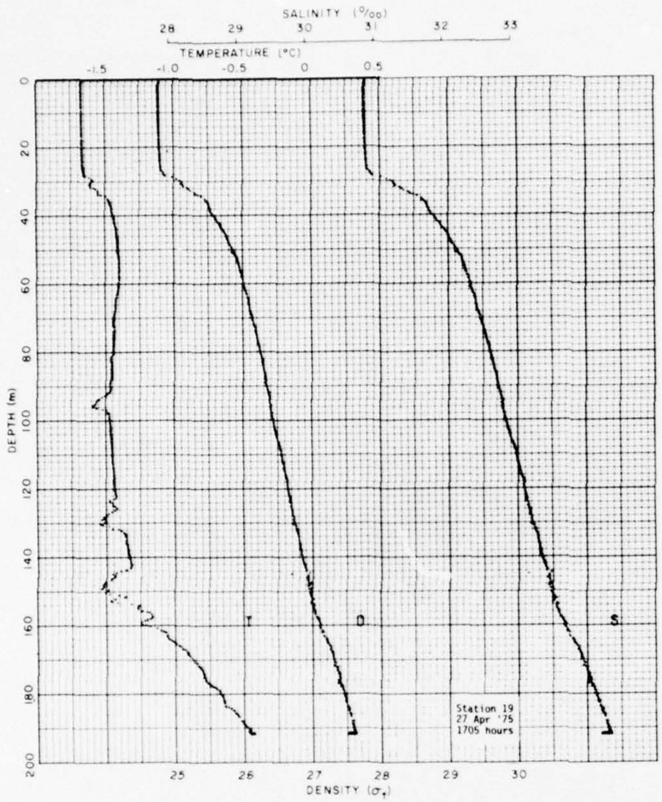

SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
DENSITY (σ_t)
25 26 27 28 29 30
T
D
S
Station 15
27 Apr '75
1242 hours


SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
D
S
Station 16
27 Apr '75
1341 hours


SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
D
D
Station 17
27 Apr '75
1439 hours


SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Nansen
Nansen
T
D
S
Bottom
Station 18
27 Apr '75
1517 hours
Cell C3


SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Nansen
Nansen
T
D
S
Station 18A
27 Apr '75
1552 hours
Cell C11

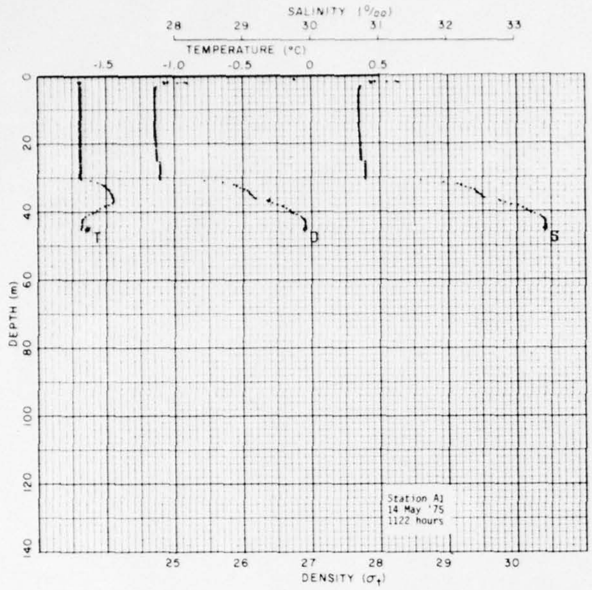

SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 20 40 60 80 100 120 140 160 180 200
T D S
Station 19
27 Apr '75
1705 hours
25 26 27 28 29 30
DENSITY (σ_t)

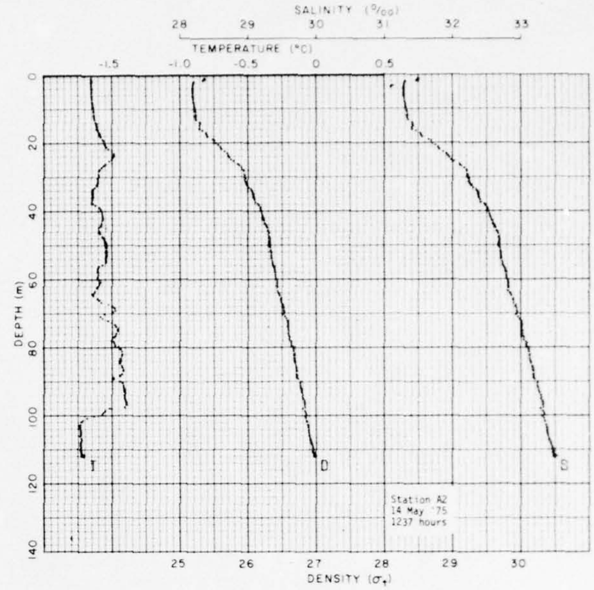
APPENDIX C

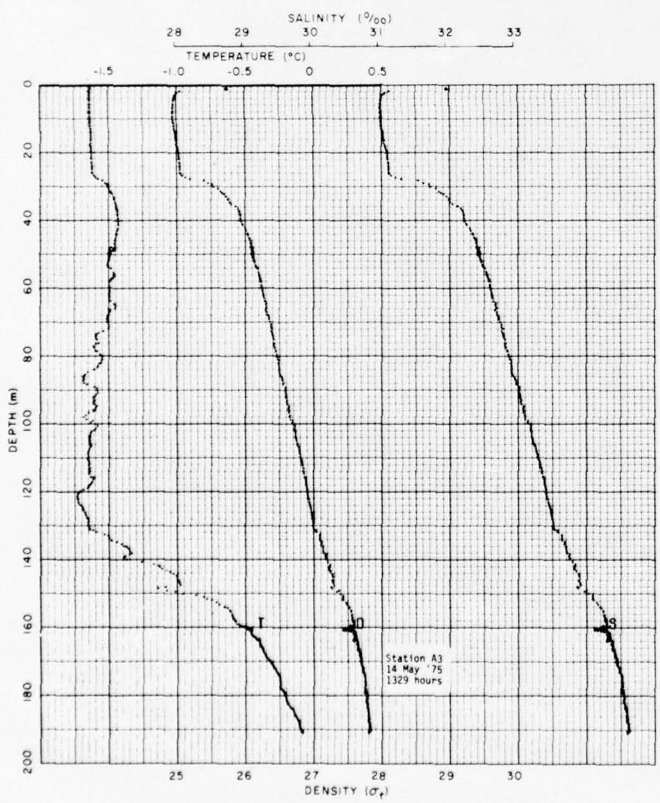
PROFILES FOR 14-19 MAY SURVEY

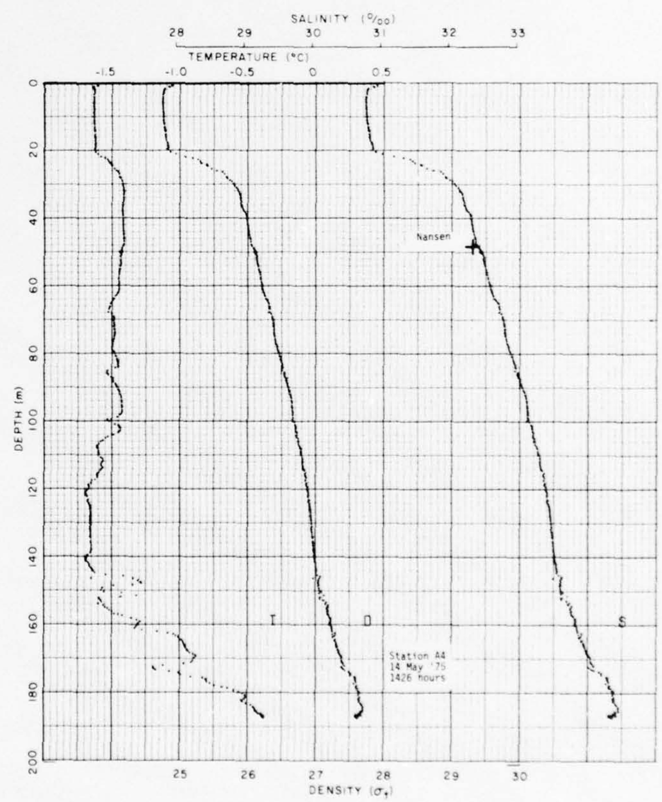
A second spring survey was conducted with the lightweight profiler in a Cessna 180 aircraft. The profiles for the 14-19 May 1975 survey are listed here and presented individually on the following pages. Station locations are shown in Figure 7, page 10.

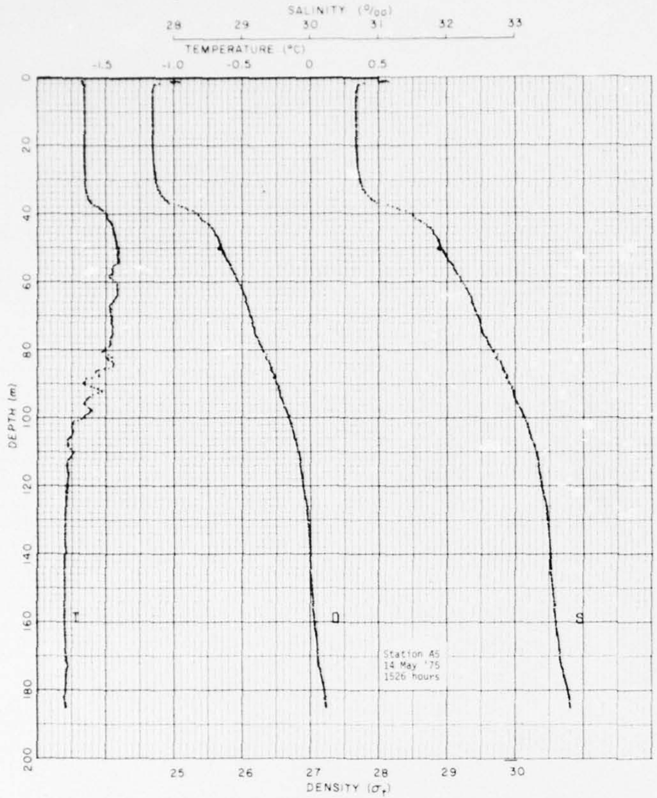
Station	Date	Time	Remarks
A1	14 May	1122	Sensors C11, T72, D3
A2		1237	
A3		1329	
A4		1426	
A5		1526	
A6		1624	
A7		1710	
A8		1805	
B1	15 May	1035	
B2		1120	
B3		1202	
B4		1340	
B4B		1410	Sensors C3, T60, D3
B5		1509	
B6		1549	
C1	19 May	1041	
C2		1220	
C3		1315	
C4		1416	
C5		1513	
C6		1730	

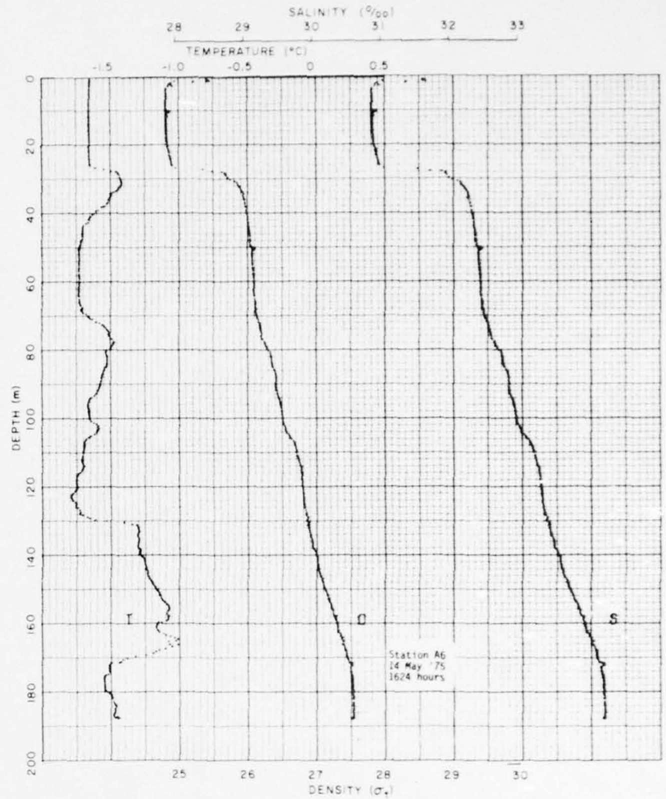

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station A1
14 May '75
1122 hours

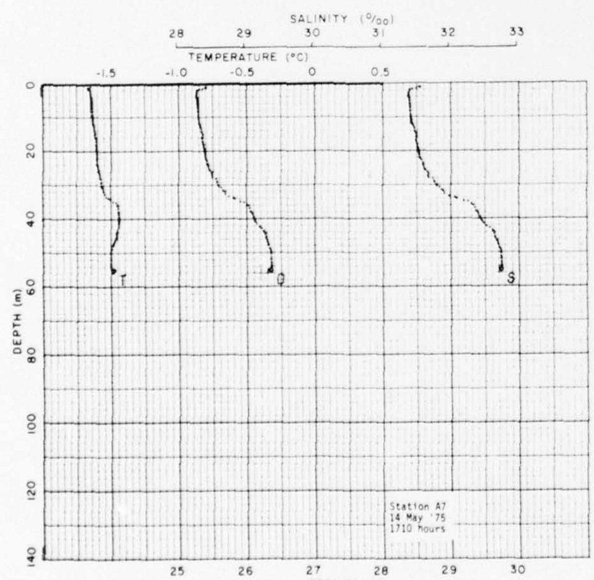

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station A2
14 May '75
1237 hours

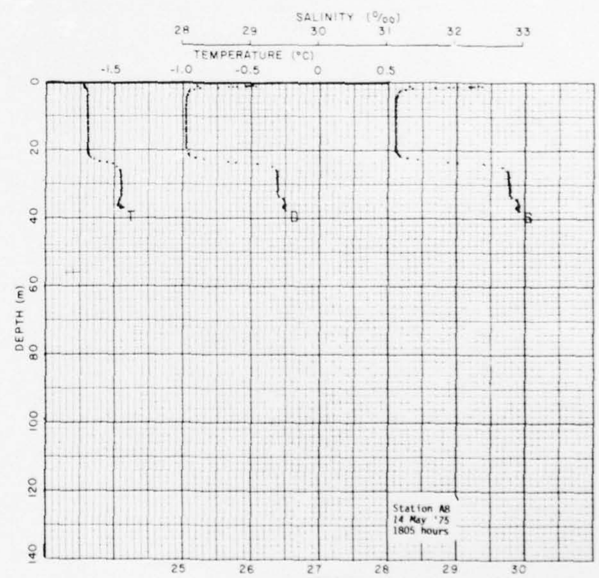

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station A3
14 May '75
1329 hours

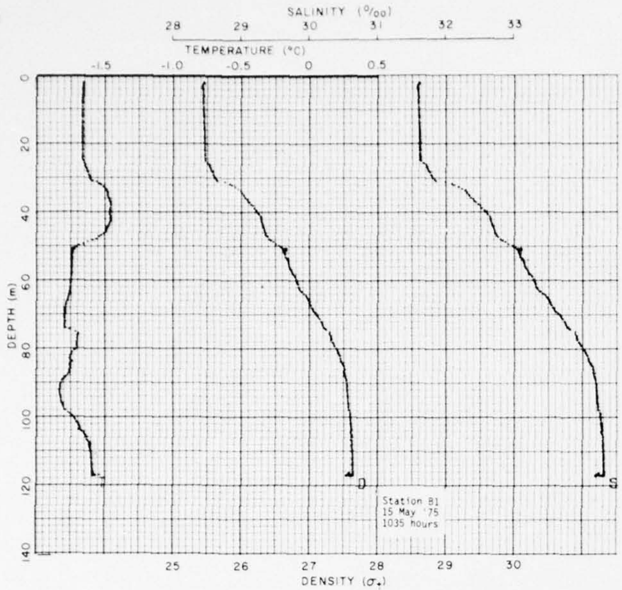

SALINITY (°/oo)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Nansen
Station A4
14 May '75
1426 hours

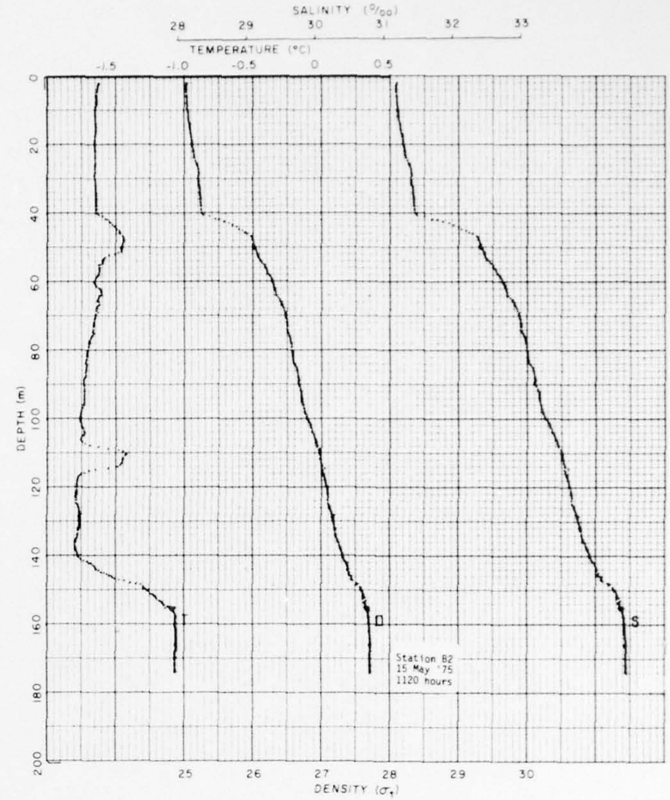

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
D
S
Station A5
14 May '75
1526 hours

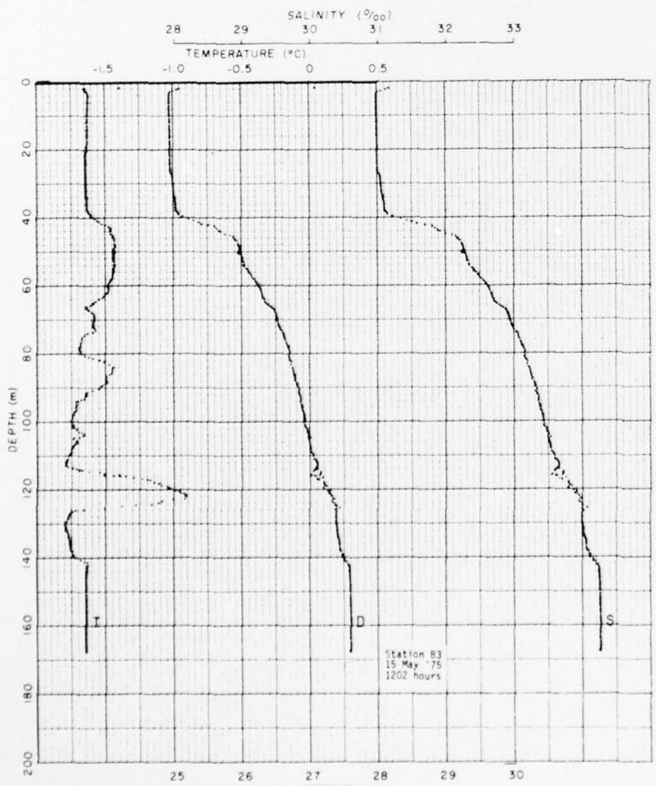

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
D
S
Station A6
14 May '75
1624 hours

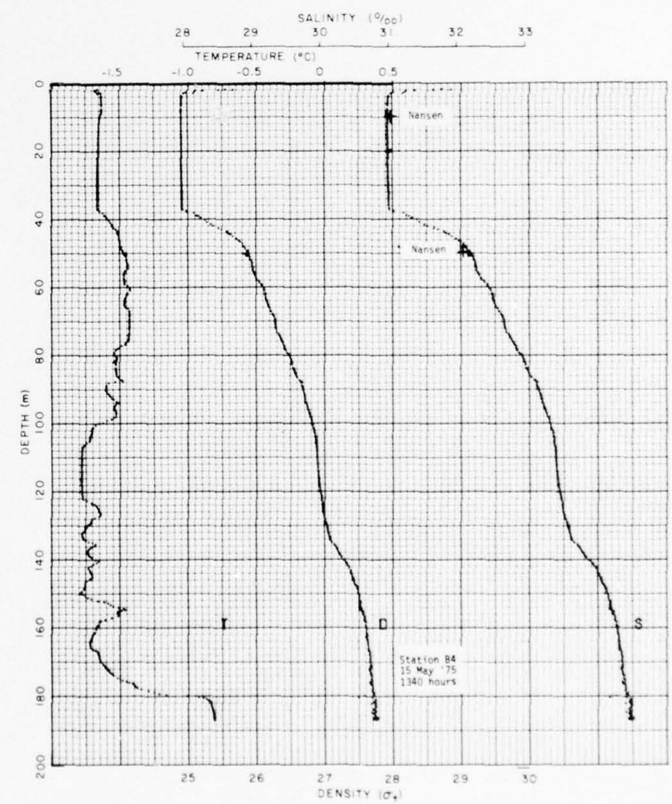

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
D
S
Station A7
14 May '75
1710 hours

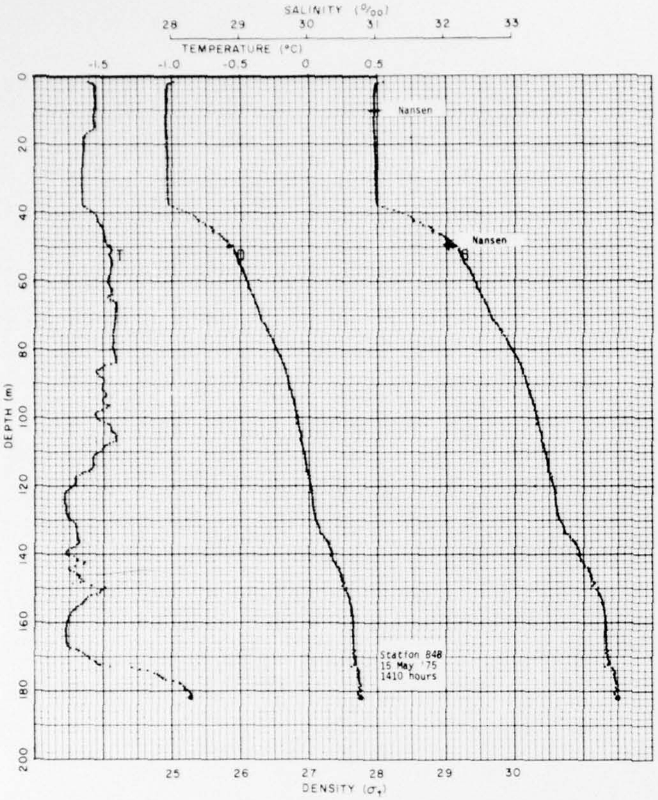

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
D
S
Station A8
14 May '75
1805 hours

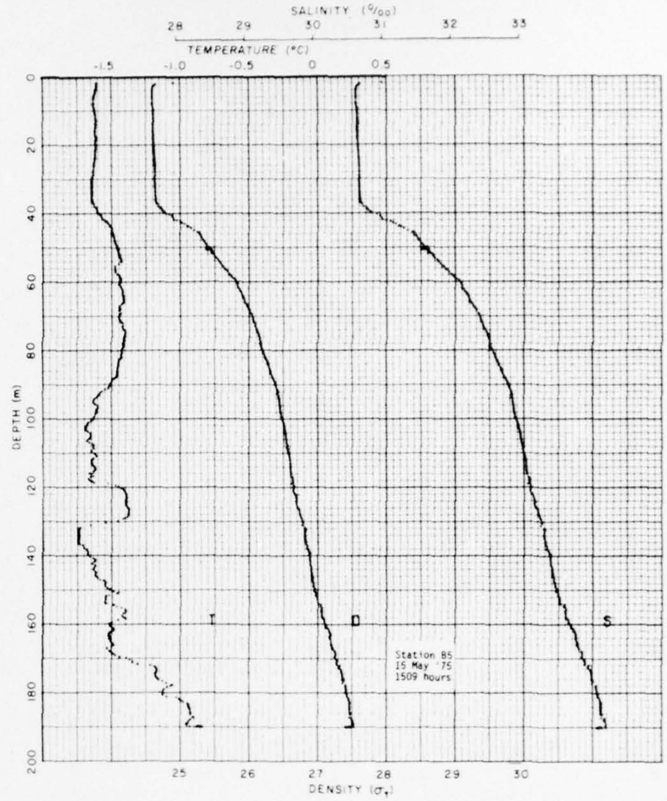

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
D
S
Station B1
15 May '75
1035 hours

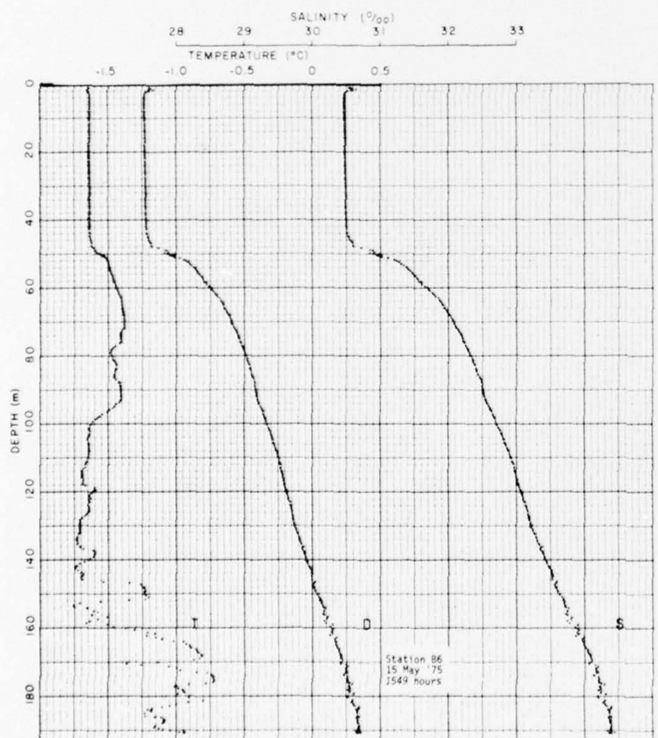

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
D
S
Station B2
15 May '75
1120 hours

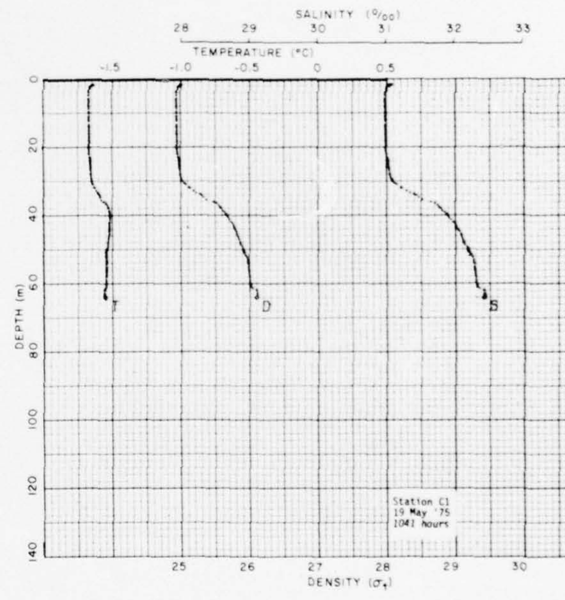

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
D
S
Station B3
15 May '75
1202 hours

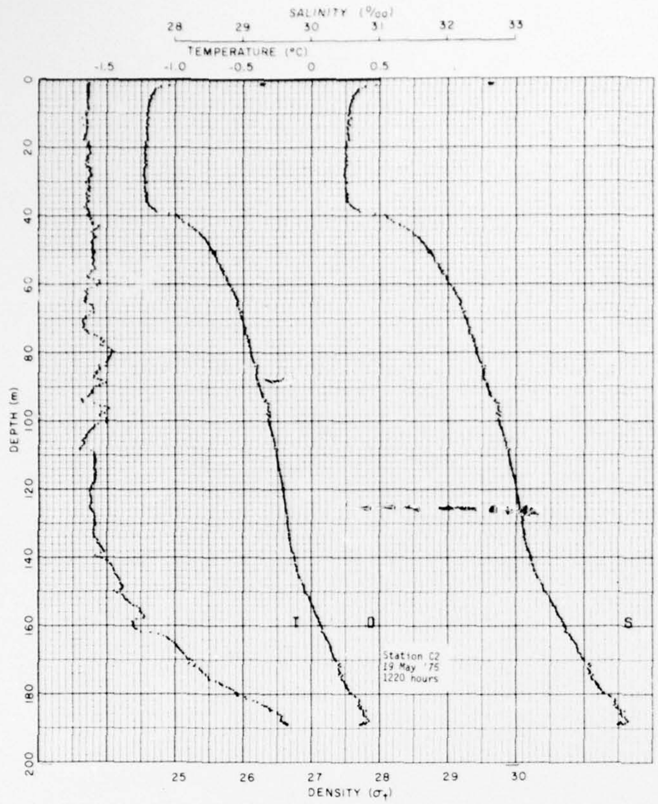

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Nansen
Nansen
T
D
S
Station B4
15 May '75
1340 hours

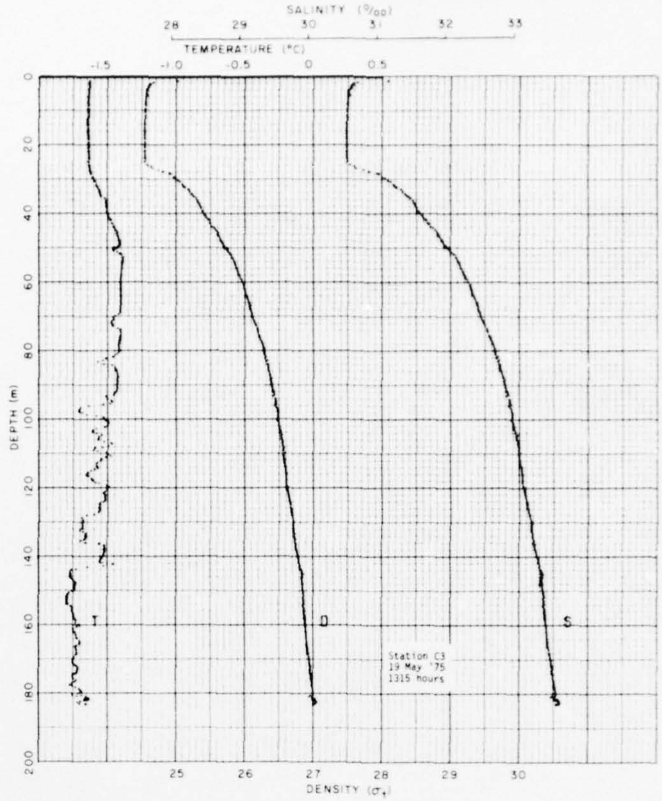

SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 20 40 60 80 100 120 140 160 180 200
Nansen
Nansen
T
D
S
Station B4B
15 May '75
1410 hours
25 26 27 28 29 30
DENSITY (σ_t)

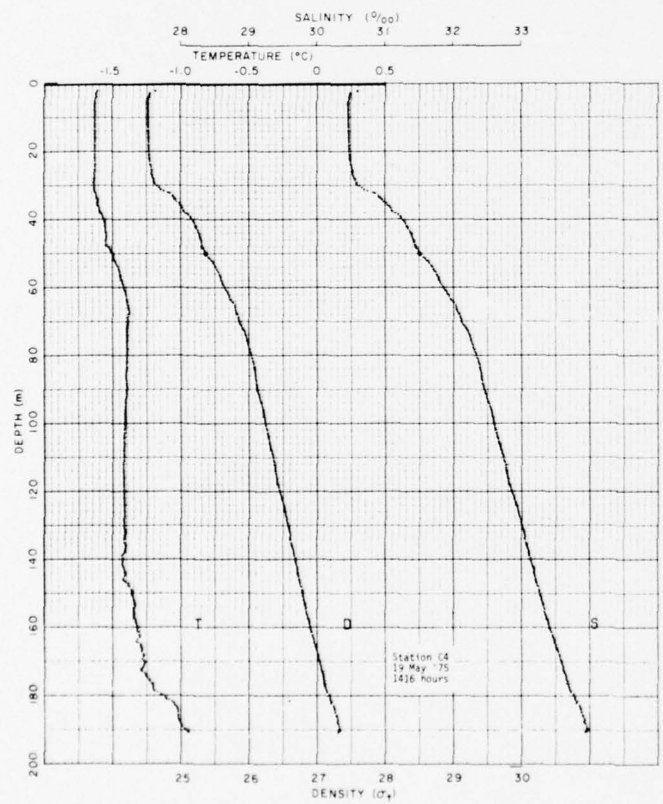

SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 20 40 60 80 100 120 140 160 180 200
T
D
S
Station B5
15 May '75
1509 hours
25 26 27 28 29 30
DENSITY (σ_t)

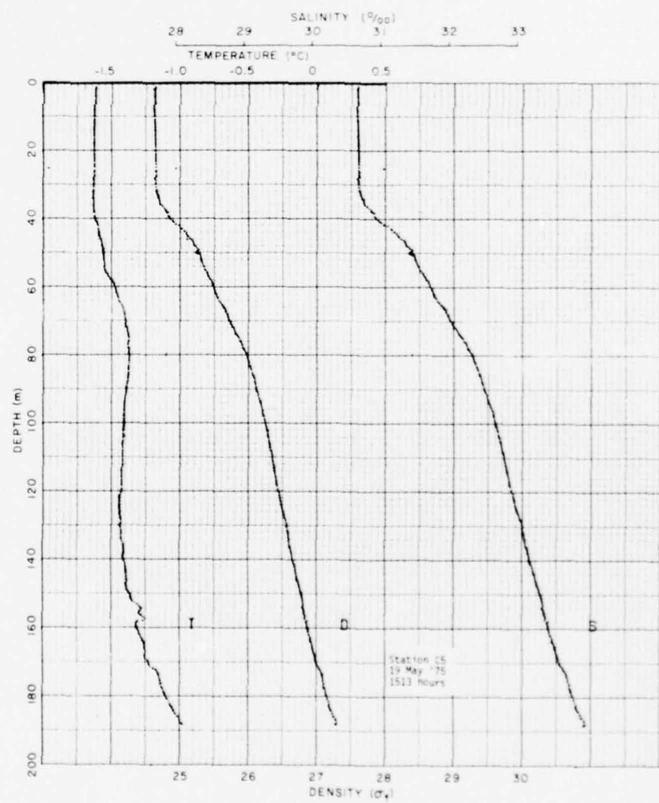

SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 20 40 60 80 100 120 140 160 180 200
T
D
S
Station B6
15 May '75
1549 hours
25 26 27 28 29 30
DENSITY (σ_t)

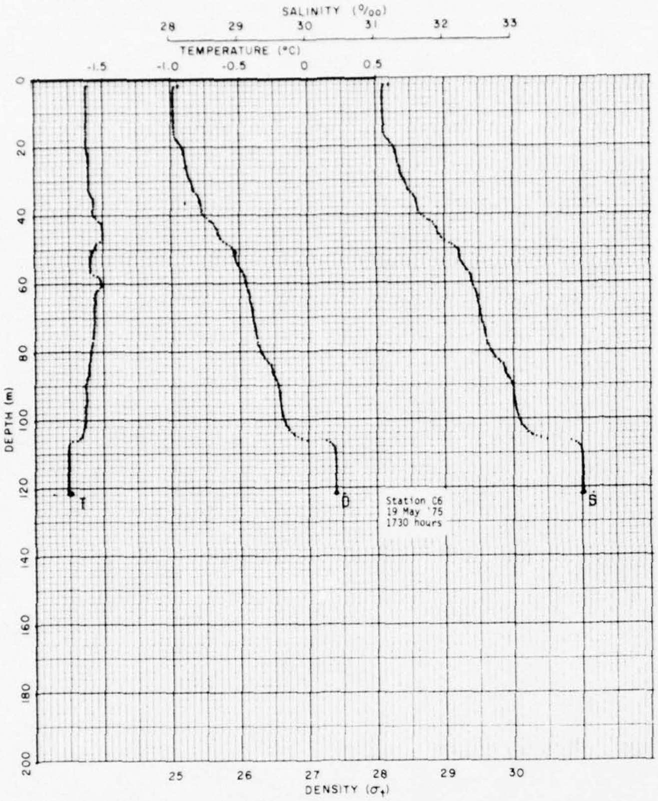

SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 20 40 60 80 100 120 140
T
D
S
Station C1
19 May '75
1041 hours
25 26 27 28 29 30
DENSITY (σ_t)


SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 20 40 60 80 100 120 140 160 180 200
T D S
Station C2
19 May '75
1220 hours
25 26 27 28 29 30
DENSITY (σt)


SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 20 40 60 80 100 120 140 160 180 200
T D S
Station C3
19 May '75
1315 hours
25 26 27 28 29 30
DENSITY (σt)


SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 20 40 60 80 100 120 140 160 180 200
T D S
Station C4
19 May '75
1416 hours
25 26 27 28 29 30
DENSITY (σt)


SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 20 40 60 80 100 120 140 160 180 200
T D S
Station C5
19 May '75
1513 hours
25 26 27 28 29 30
DENSITY (σt)



SALINITY (‰)
28 29 30 31 32 33
TEMPERATURE (°C)
-1.5 -1.0 -0.5 0 0.5
DEPTH (m)
0 20 40 60 80 100 120 140 160 180 200
T
D
S
Station C6
19 May '75
1730 hours
25 26 27 28 29 30
DENSITY (σ_t)

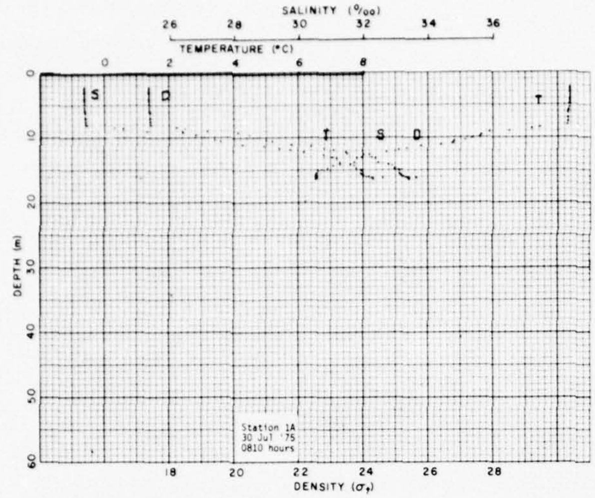
APPENDIX D

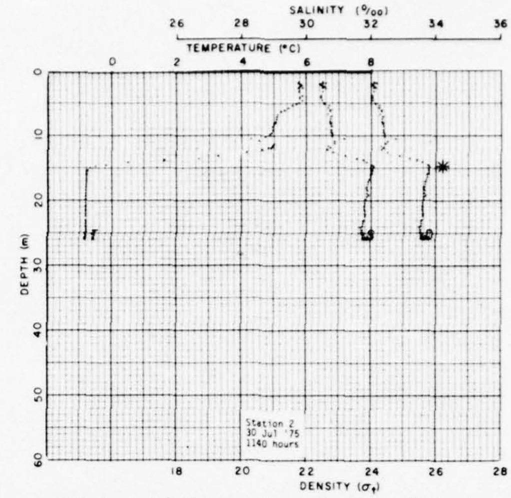
PROFILES FOR JULY-AUGUST NOME TO WAINWRIGHT CRUISE

A cruise on the icebreaker USCGC GLACIER from Nome to Wainwright provided an opportunity for the oceanographic stations listed below. The temperature, salinity and density profiles for each station are included. A chart of the station locations is shown in Figure 17, page 21.

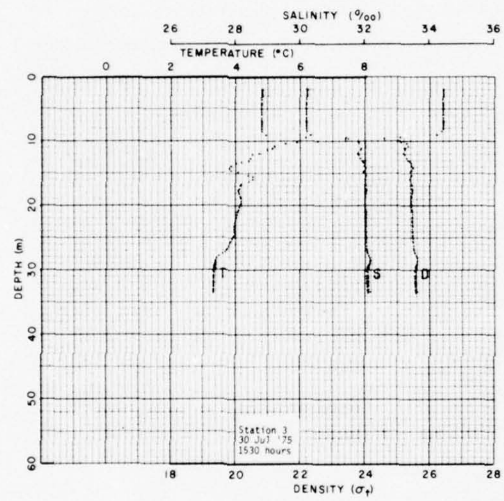
Station	Date	Time	Station	Date	Time
1A	30 July	0810	37E		1358
2		1140	38		1610
3		1530	39		1745
4		1925	40		1935
5		2315	41		2040
6	31 July	0400	42		2204
7		0700	43	3 Aug	0315
8		0939	44		0435
9		1230	45		0545
10		1630	46		0650
11		2130	47		1015
12	1 Aug	0100	49		1300
13		0200	50		1400
14		0410	51		1630
15		0630	52		1830
16		0840	53		2140
18		1200	54	4 Aug	0130
22		1730	55		0500
23		1805	56		1020
24		1840	59		1445
25		2005	60		1545
26		2245	61		1730
27	2 Aug	0130	63A	5 Aug	0230
29		0340	63B		0315
31		0515	64		0350
32		0615	65A		0500
33		0715	66		0630
34		0810	67		0715
35		0900	68		0815
36		1110	69		1025
37A		1215	70		1225
37B		1225	71		1350
37C		1235	72		1600
37D		1245	73		1705

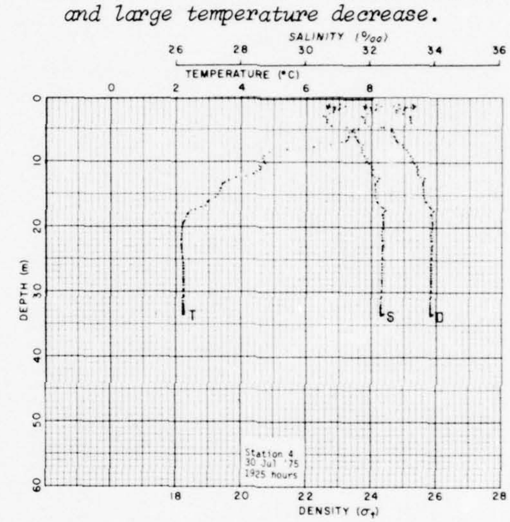
Station	Date	Time	Station	Date	Time
74		1830	104		2340
75		2005	105	8 Aug	0159
76		2130	106		0320
77		2245	107		0412
78	6 Aug	0030	108		0525
79		0230	109		0630
80		0345	110		0735
81		0500	111		0830
82		0645	112		1003
83		0820	113		1100
84		0917	114		1215
85		1110	115		1413
86		1200	116		1553
87		1300	117		1815
88		1400	118		2020
89		1630	119		2140
90		1800	120		2330
91		2045	121	9 Aug	0330
92		2125	122		0655
93	7 Aug	0020	123		1045
94		0110	125		1445
95		0150	126		1620
96		0230	127		1745
98A		0508	128		2005
99		0645	129	10 Aug	0600
100		0840	130		2300
101		1632	132	11 Aug	1025
102		1820	137		1355
103		2015	138		1545

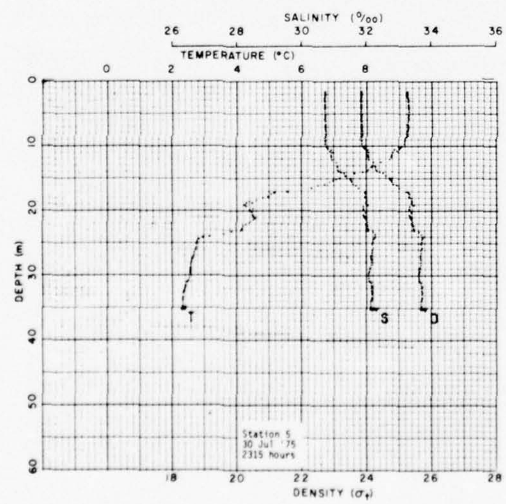


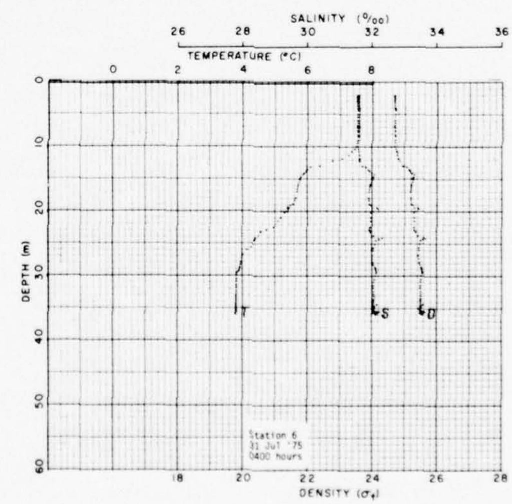


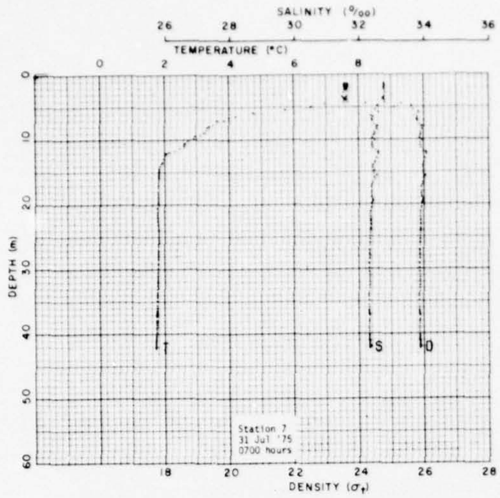
*High salinity values believed to be erroneous and related to the sudden and large temperature decrease.

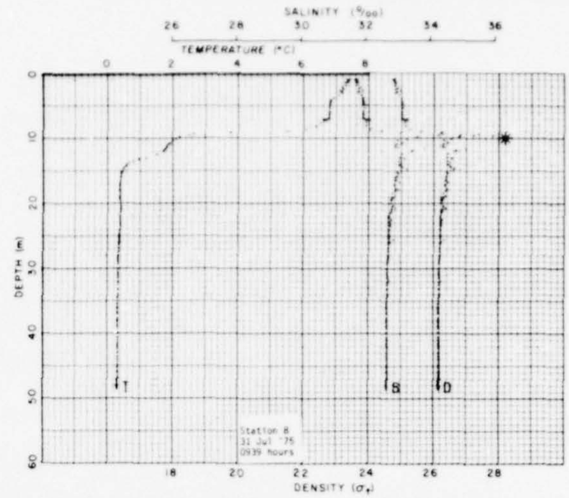




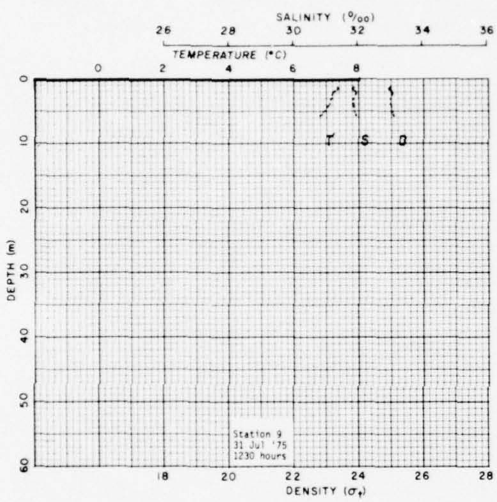


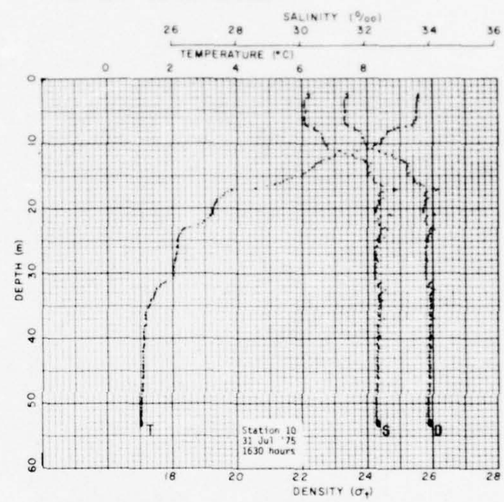


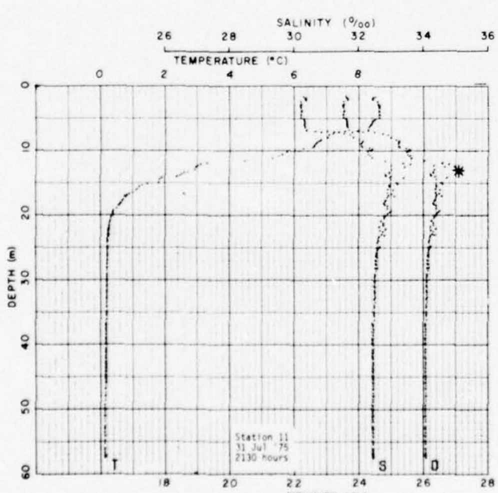




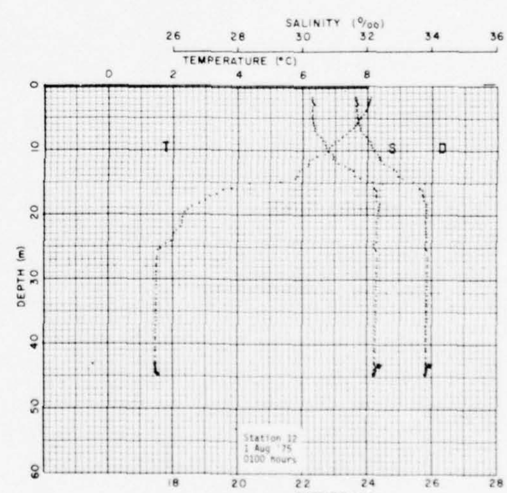
*High salinity values believed to be erroneous.

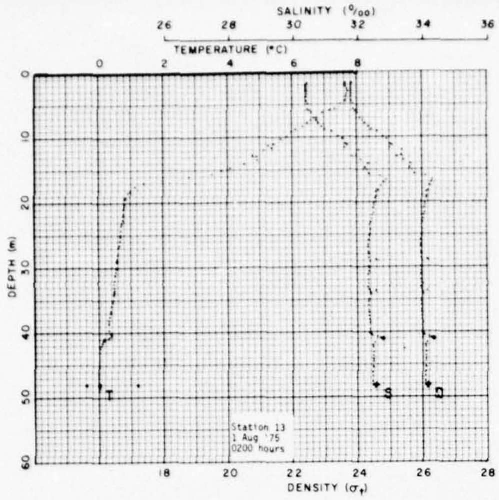


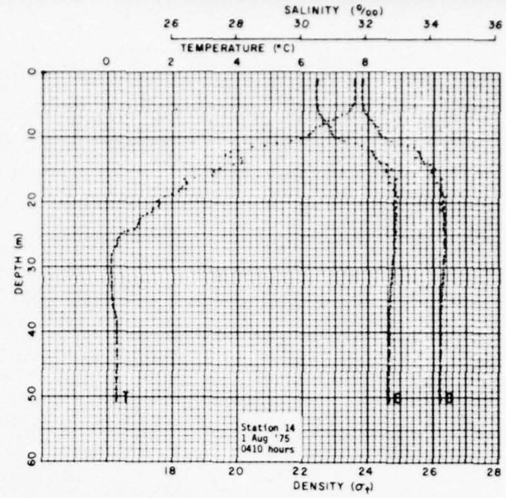


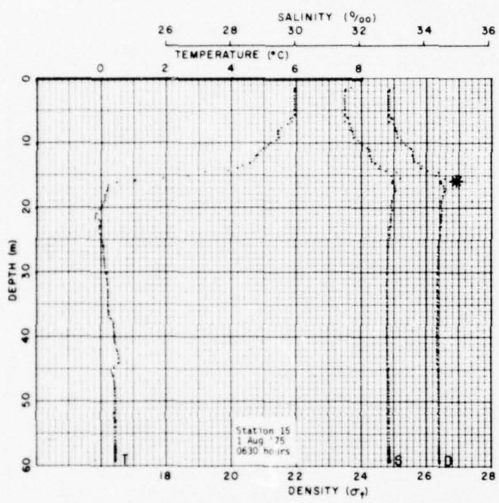


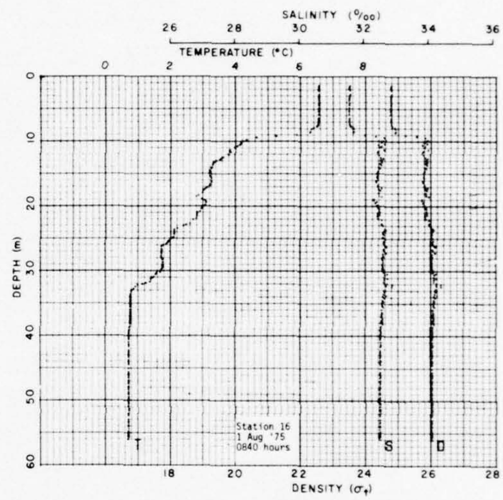
*High salinity values believed to be erroneous.



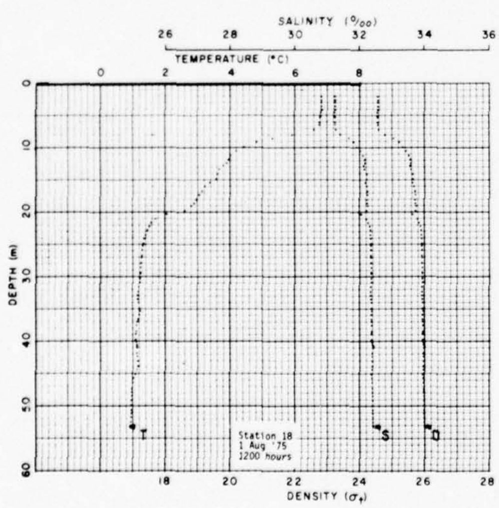


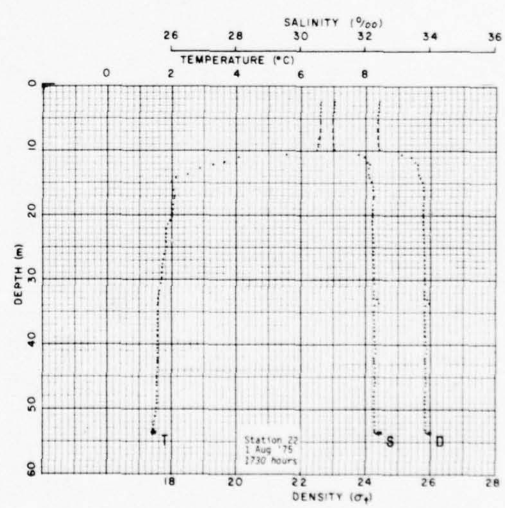


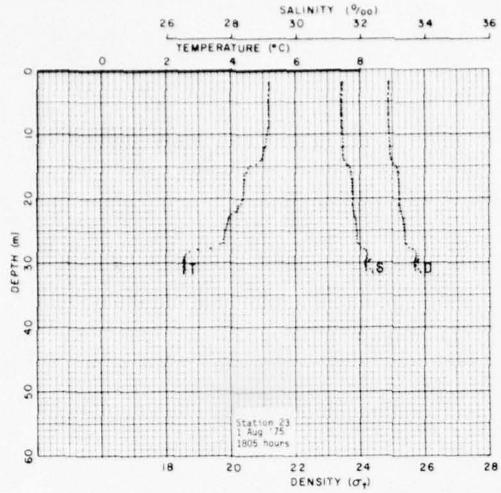


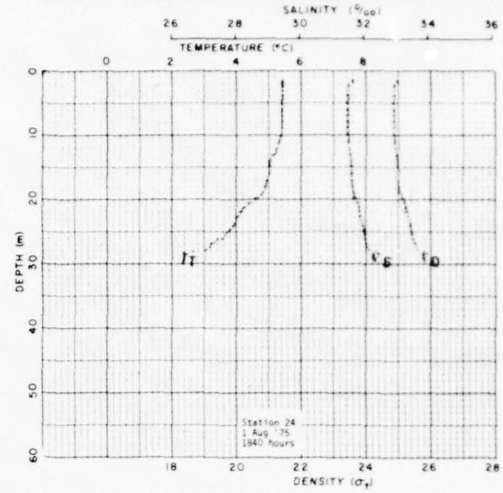


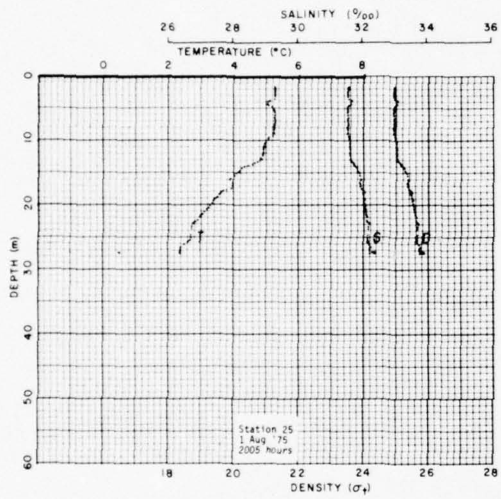
*High salinity values believed to be erroneous.

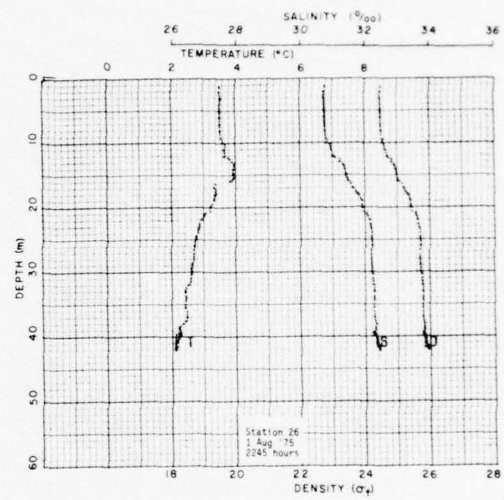


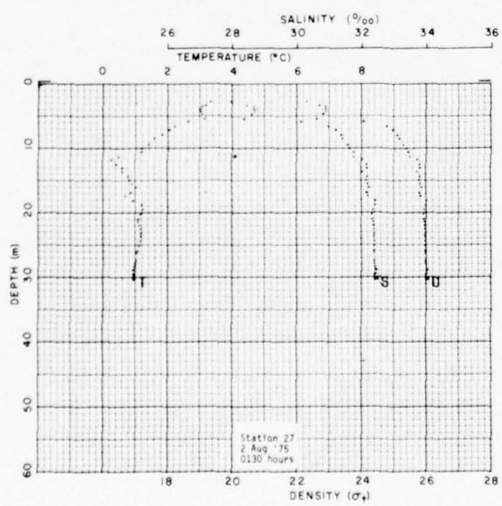


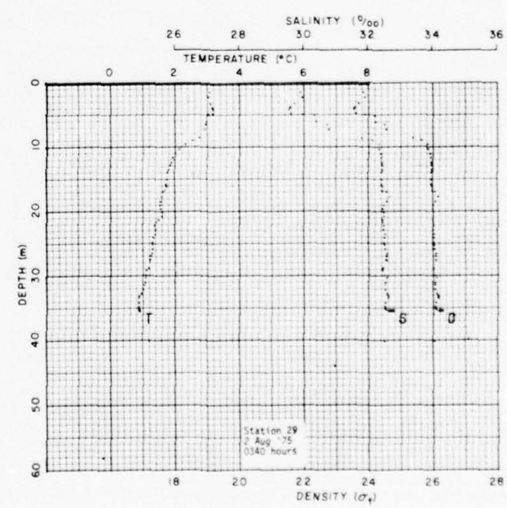

SALINITY (0/00)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station 23
1 Aug '75
1805 hours

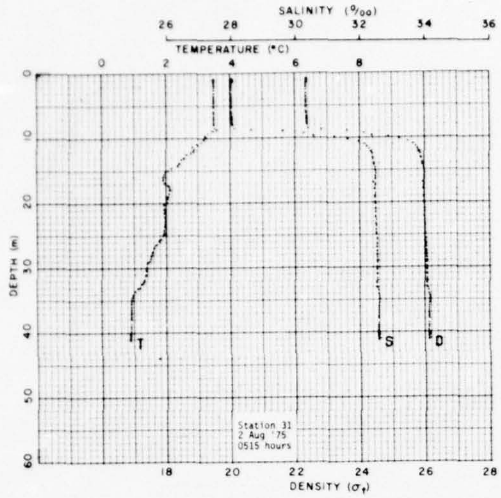

SALINITY (0/00)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station 24
1 Aug '75
1840 hours

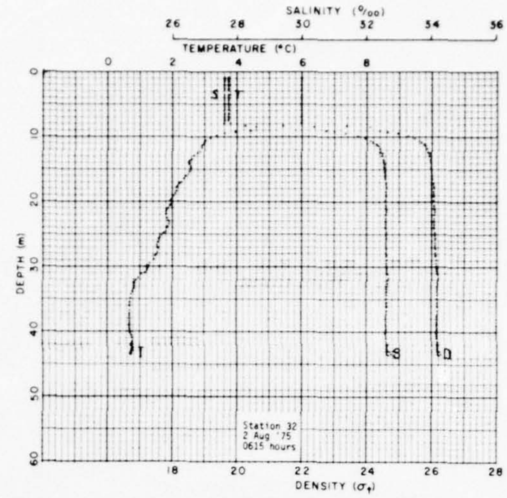

SALINITY (0/00)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station 25
1 Aug '75
2005 hours

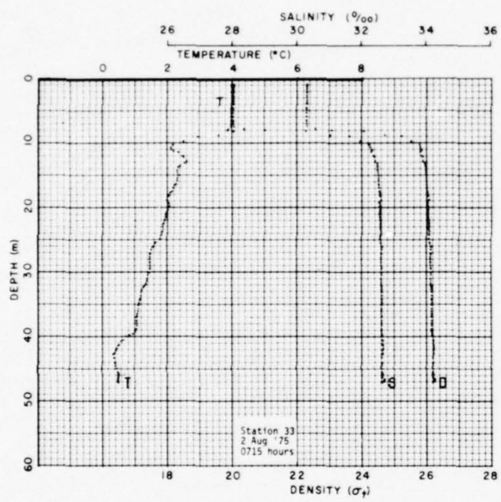

SALINITY (0/00)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station 26
1 Aug '75
2245 hours

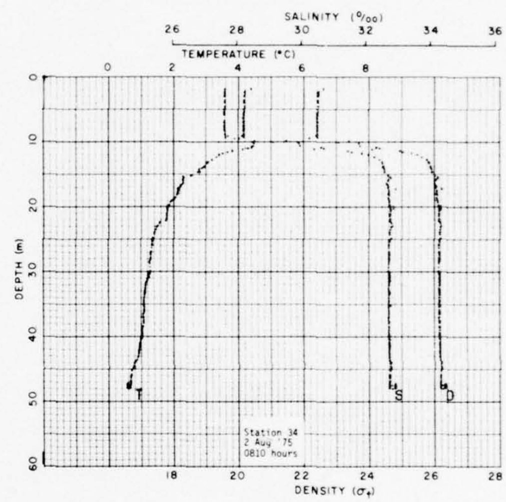

SALINITY (0/00)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station 27
2 Aug '75
0130 hours

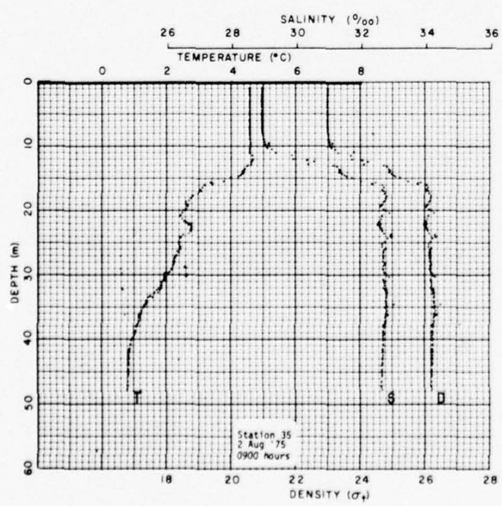

SALINITY (0/00)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station 29
2 Aug '75
0340 hours

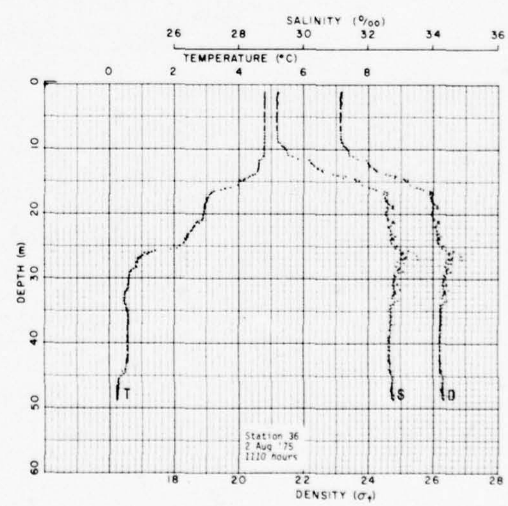

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 31
2 Aug '75
0515 hours
18 20 22 24 26 28
DENSITY (σ_t)

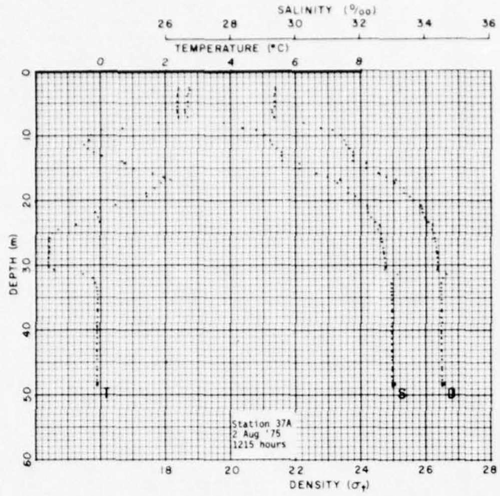

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
S T
T
S
D
Station 32
2 Aug '75
0615 hours
18 20 22 24 26 28
DENSITY (σ_t)

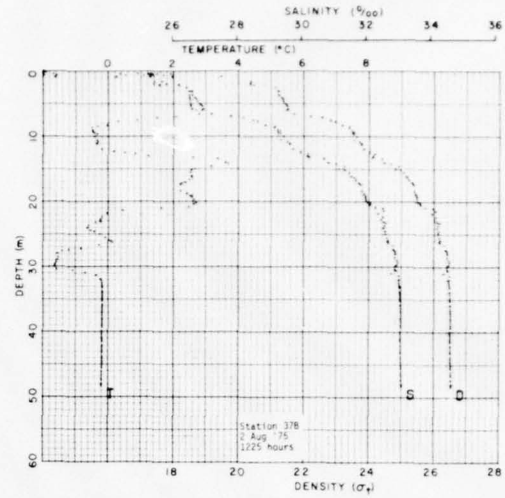

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
T
S
D
Station 33
2 Aug '75
0715 hours
18 20 22 24 26 28
DENSITY (σ_t)

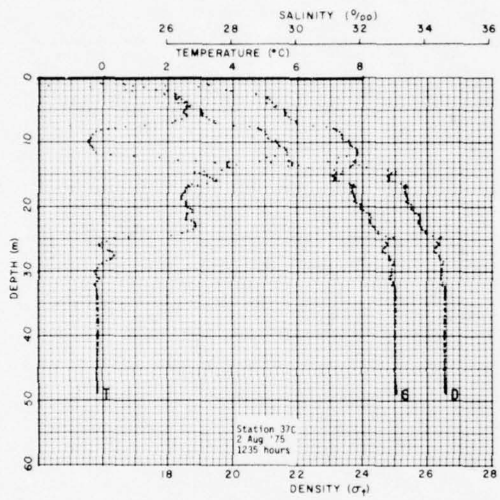

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 34
2 Aug '75
0810 hours
18 20 22 24 26 28
DENSITY (σ_t)

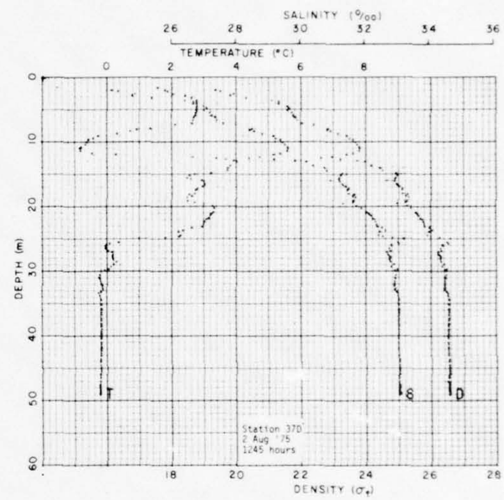

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 35
2 Aug '75
0900 hours
18 20 22 24 26 28
DENSITY (σ_t)

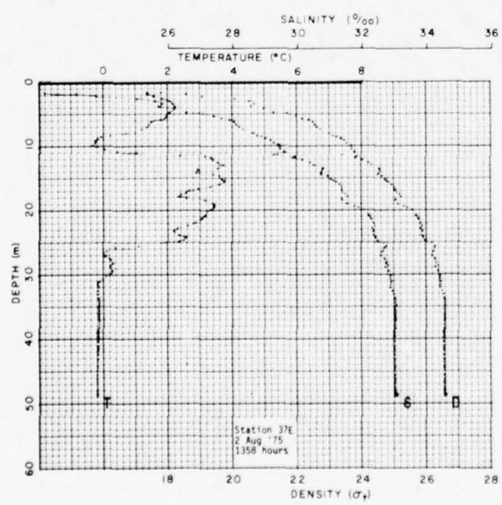

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 36
2 Aug '75
1110 hours
18 20 22 24 26 28
DENSITY (σ_t)

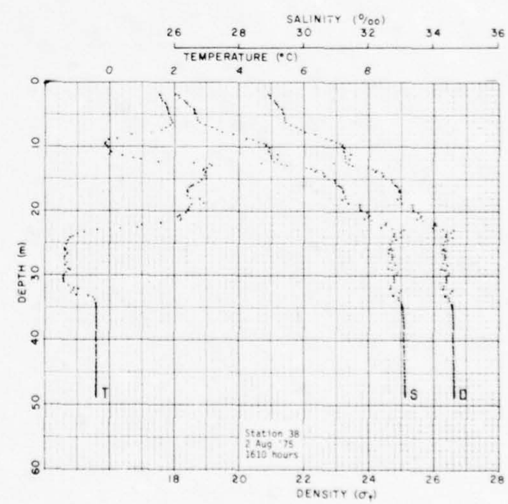

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 37A
2 Aug '75
1215 hours

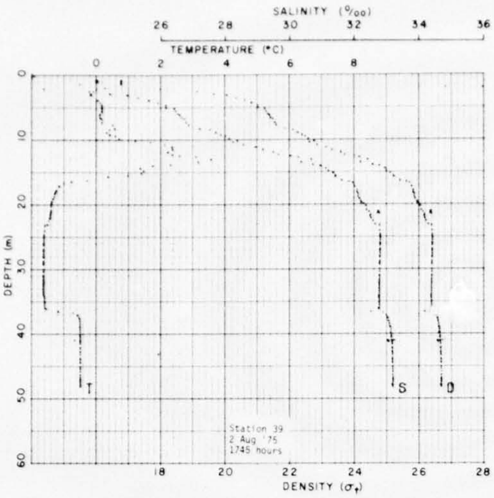

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 37B
2 Aug '75
1225 hours

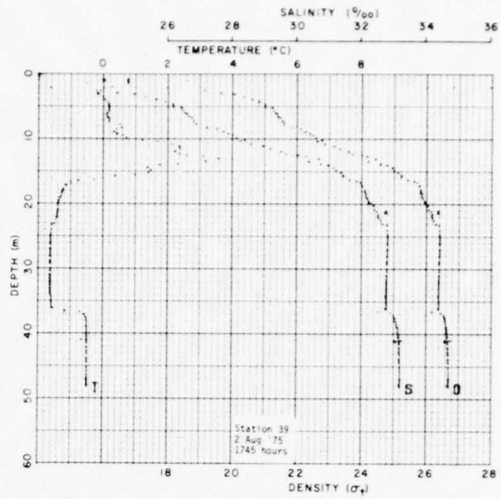

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 37C
2 Aug '75
1235 hours

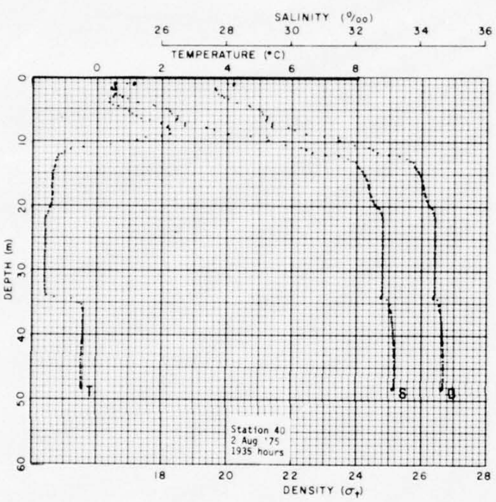

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 37D
2 Aug '75
1245 hours

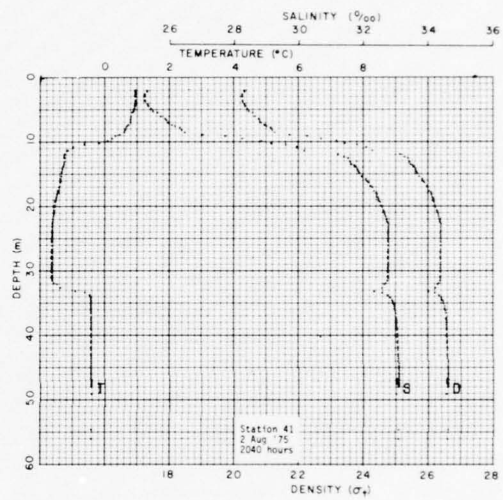

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 37E
2 Aug '75
1358 hours

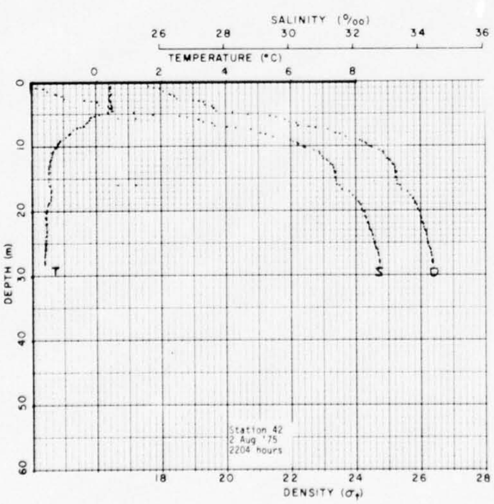

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 38
2 Aug '75
1610 hours

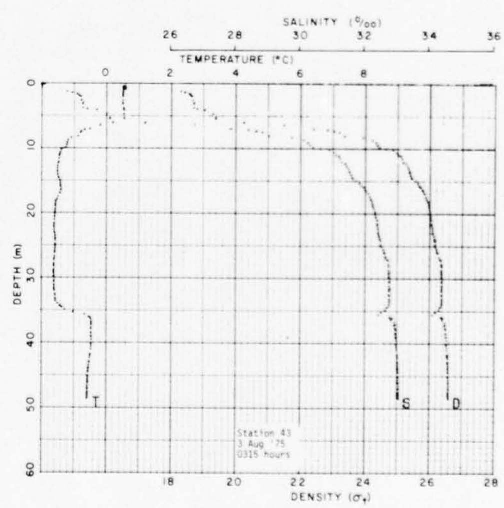

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 39
2 Aug '75
1745 hours

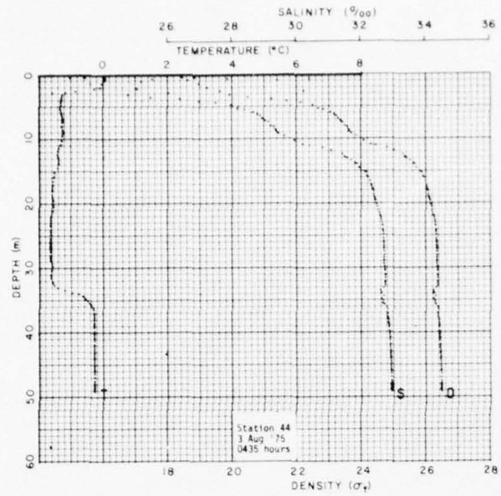

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 39
2 Aug '75
1745 hours

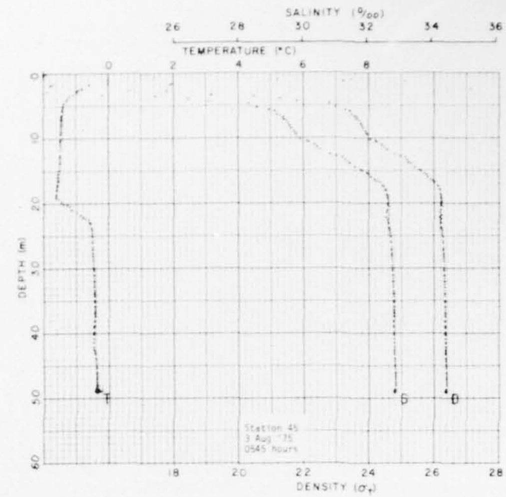

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 40
2 Aug '75
1935 hours

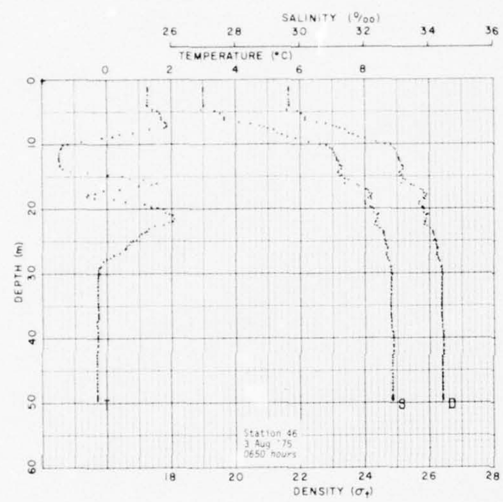

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 41
2 Aug '75
2040 hours

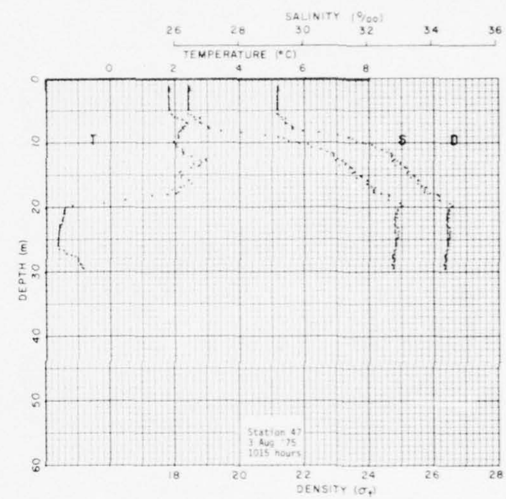

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 42
2 Aug '75
2204 hours

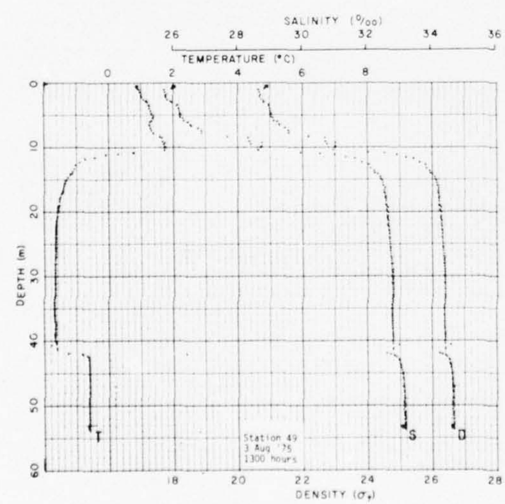

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 43
3 Aug '75
0315 hours

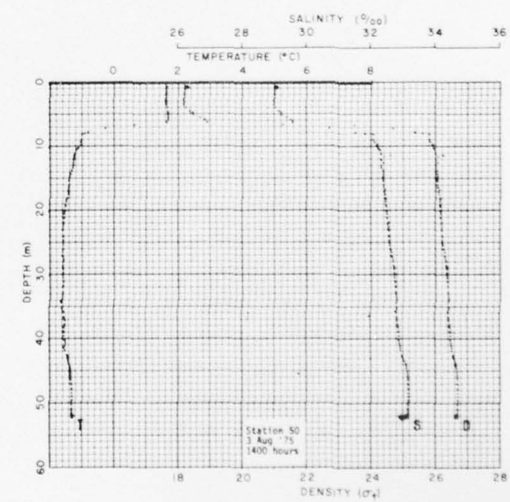

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station 44
3 Aug '75
0435 hours

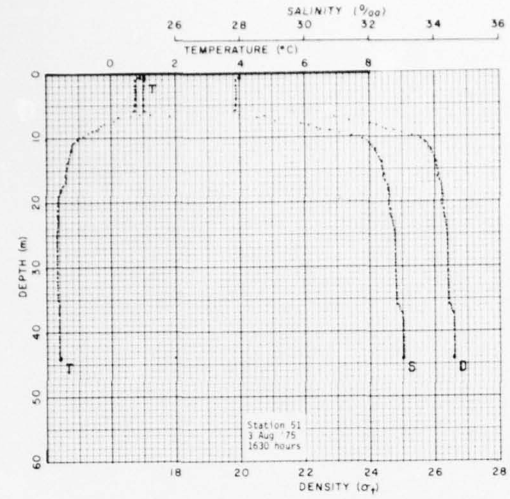

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station 45
3 Aug '75
0545 hours

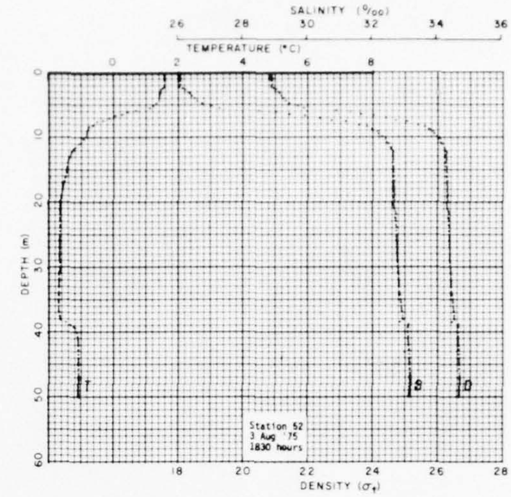

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station 46
3 Aug '75
0650 hours

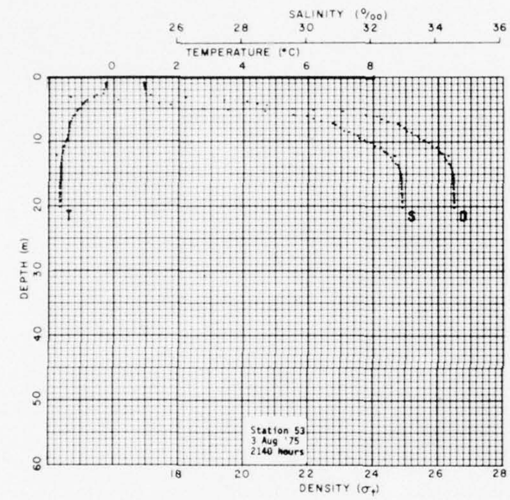

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station 47
3 Aug '75
1015 hours

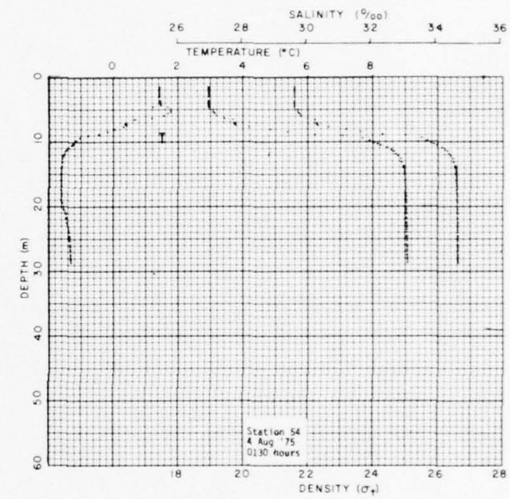

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station 49
3 Aug '75
1300 hours

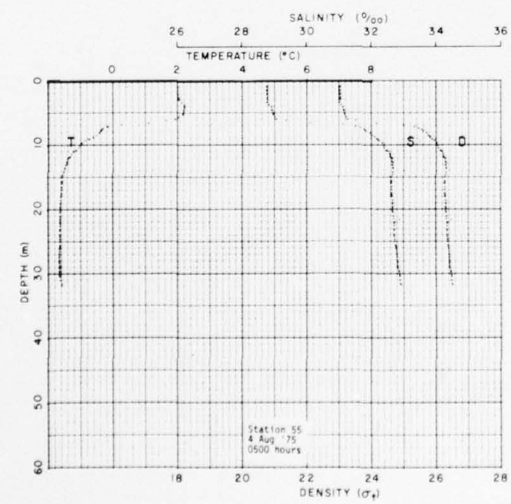

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
Station 50
3 Aug '75
1400 hours

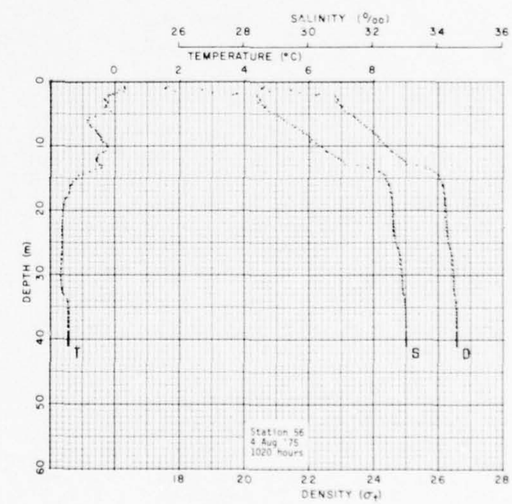

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 51
3 Aug '75
1630 hours
18 20 22 24 26 28
DENSITY (σ_t)

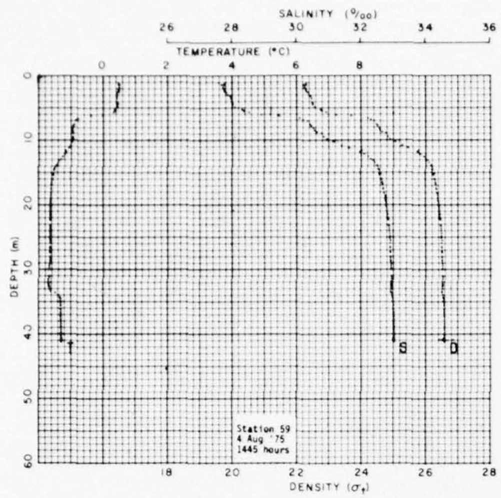

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 52
3 Aug '75
1830 hours
18 20 22 24 26 28
DENSITY (σ_t)

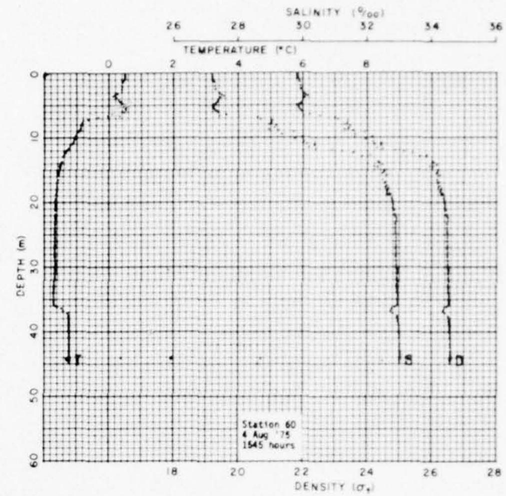

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 53
3 Aug '75
2140 hours
18 20 22 24 26 28
DENSITY (σ_t)

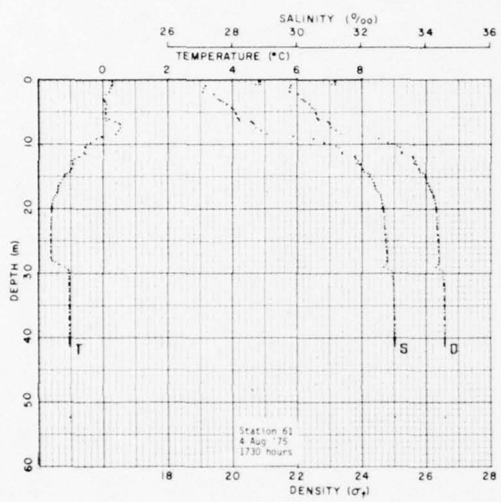

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
Station 54
4 Aug '75
0130 hours
18 20 22 24 26 28
DENSITY (σ_t)

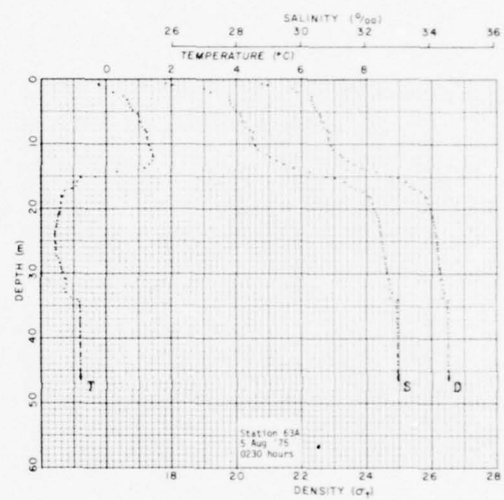

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 55
4 Aug '75
0500 hours
18 20 22 24 26 28
DENSITY (σ_t)

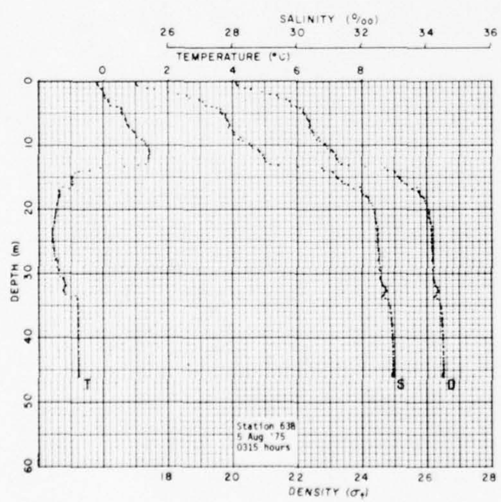

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 56
4 Aug '75
1020 hours
18 20 22 24 26 28
DENSITY (σ_t)

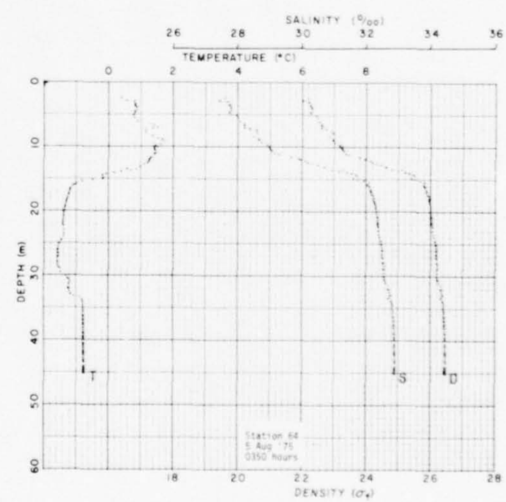

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 59
4 Aug '75
1445 hours
18 20 22 24 26 28
DENSITY (σt)

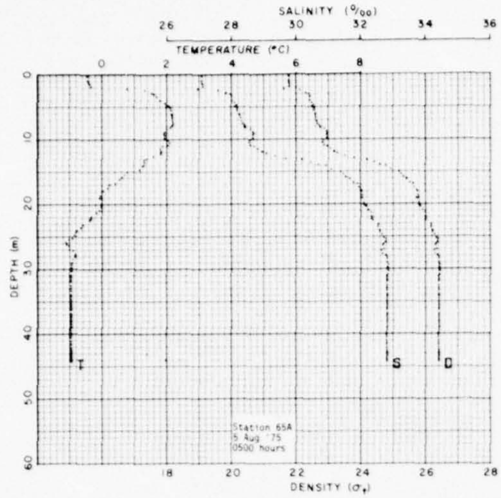

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 60
4 Aug '75
1645 hours
18 20 22 24 26 28
DENSITY (σt)

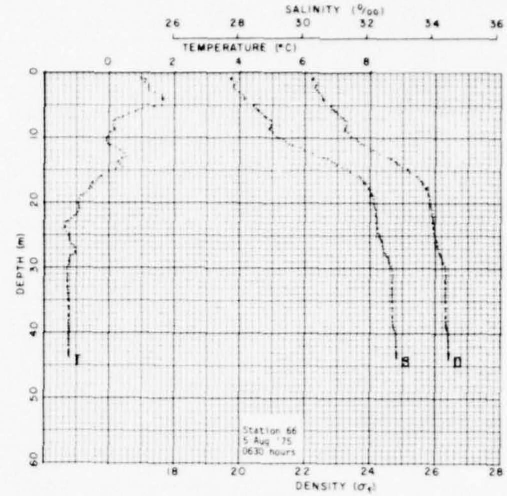

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 61
4 Aug '75
1730 hours
18 20 22 24 26 28
DENSITY (σt)

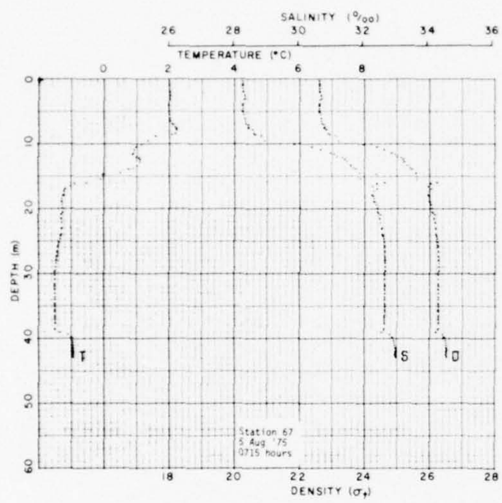

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 63A
5 Aug '75
0230 hours
18 20 22 24 26 28
DENSITY (σt)

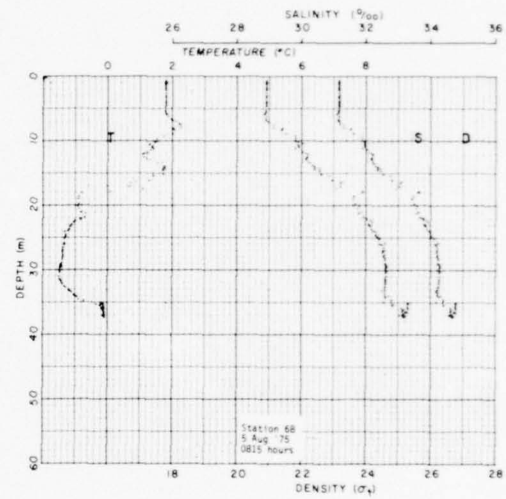

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 63B
5 Aug '75
0315 hours
18 20 22 24 26 28
DENSITY (σt)

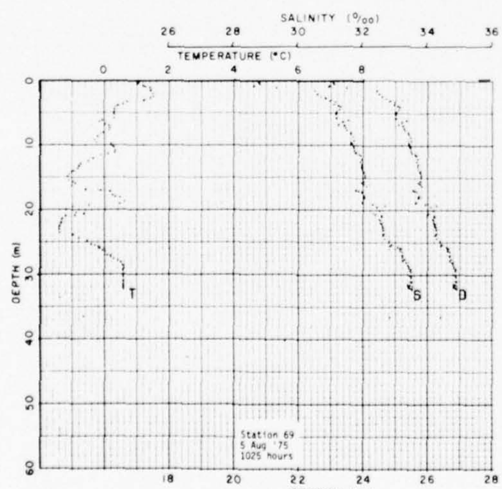

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T
S
D
Station 64
5 Aug '75
0350 hours
18 20 22 24 26 28
DENSITY (σt)

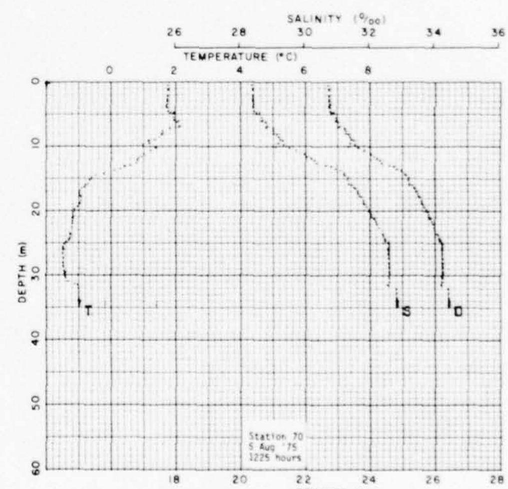

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 65A
5 Aug '75
0500 hours

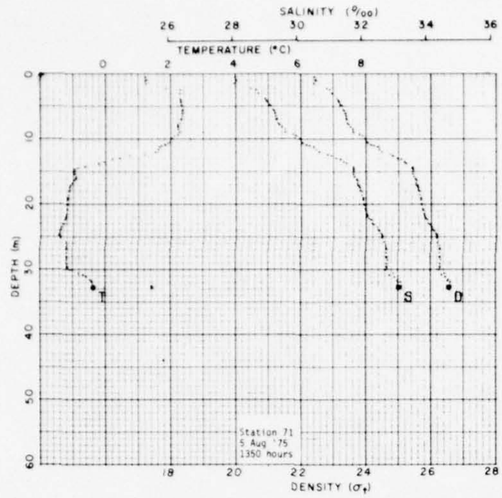

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 66
5 Aug '75
0630 hours

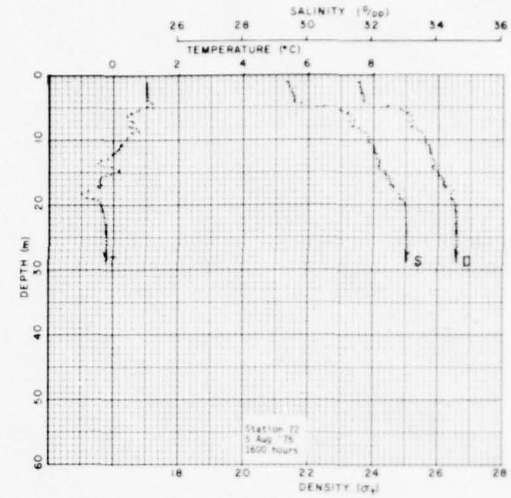

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 67
5 Aug '75
0715 hours

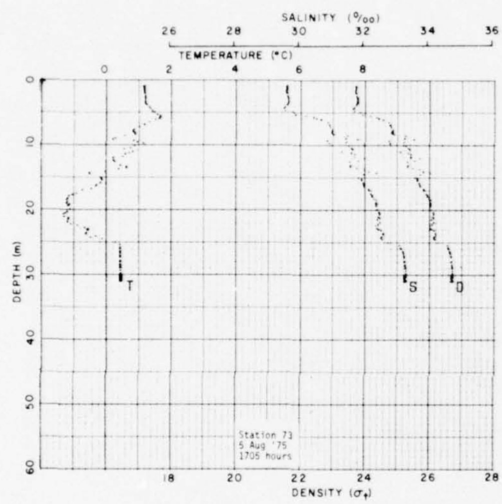

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 68
5 Aug '75
0815 hours

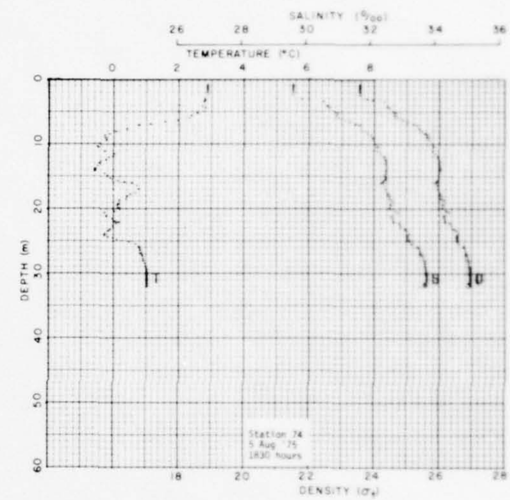

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 69
5 Aug '75
1025 hours

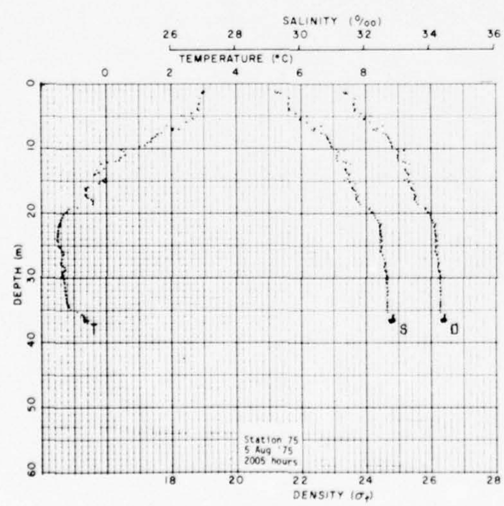

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 70
5 Aug '75
1225 hours

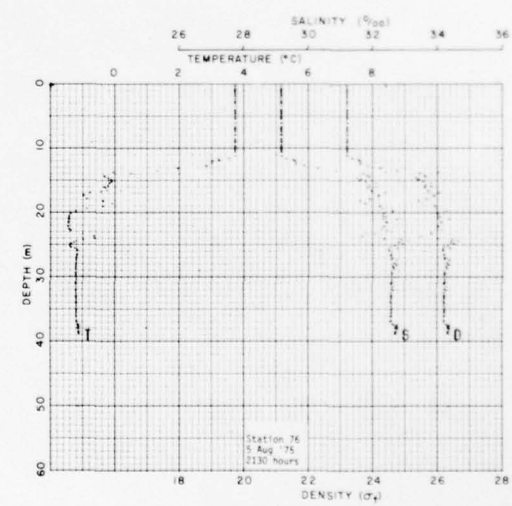

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 71
5 Aug '75
1350 hours

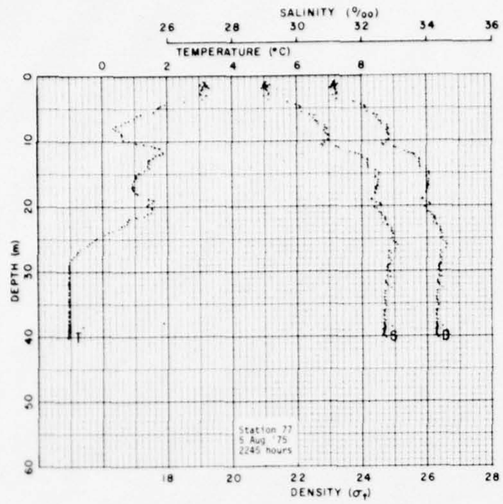

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 72
5 Aug '75
1600 hours

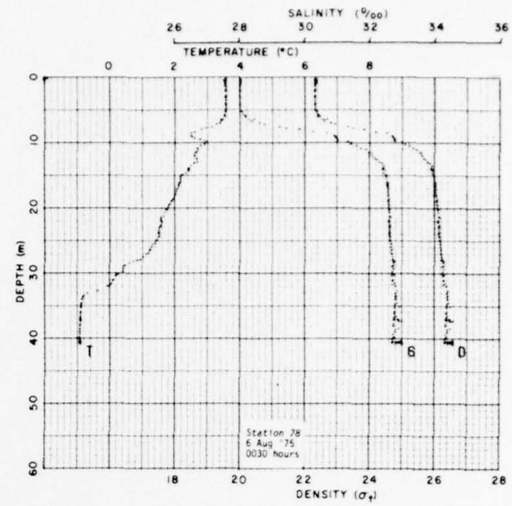

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 73
5 Aug '75
1705 hours

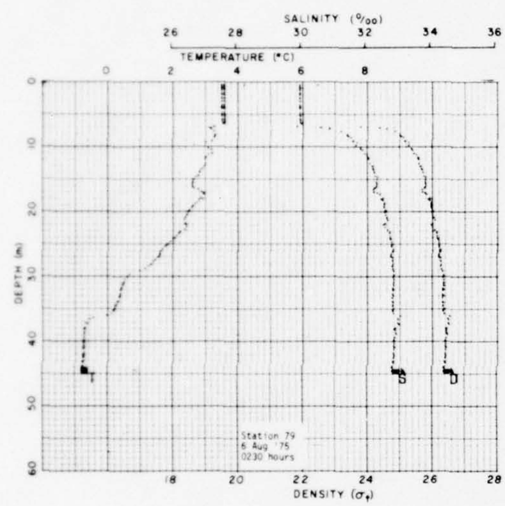

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 74
5 Aug '75
1830 hours

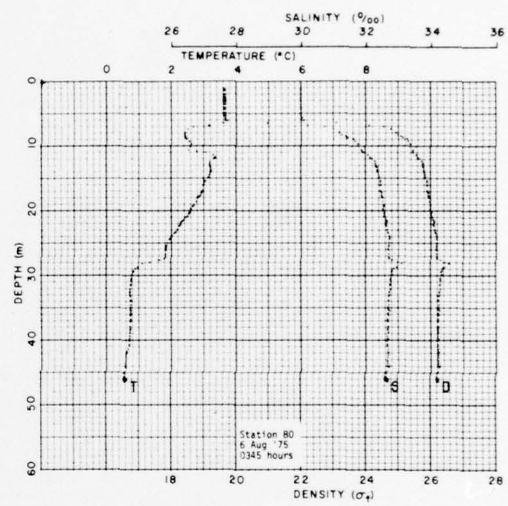

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 75
5 Aug '75
2005 hours

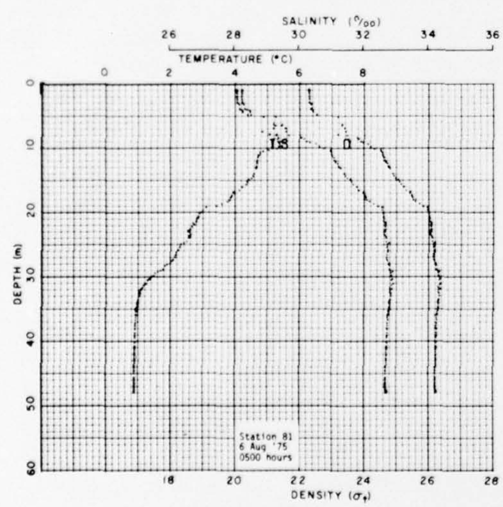

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 76
5 Aug '75
2130 hours

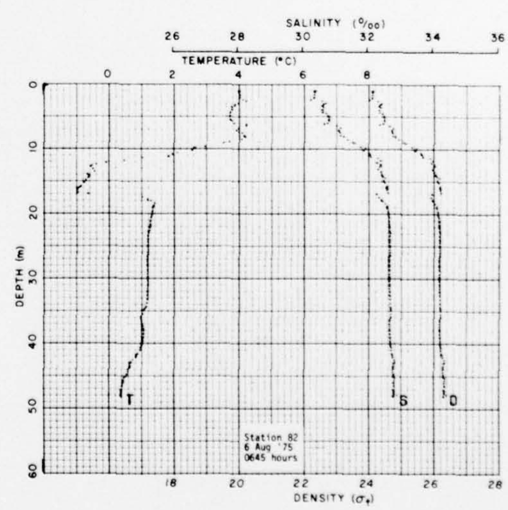

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 77
5 Aug '75
2245 hours

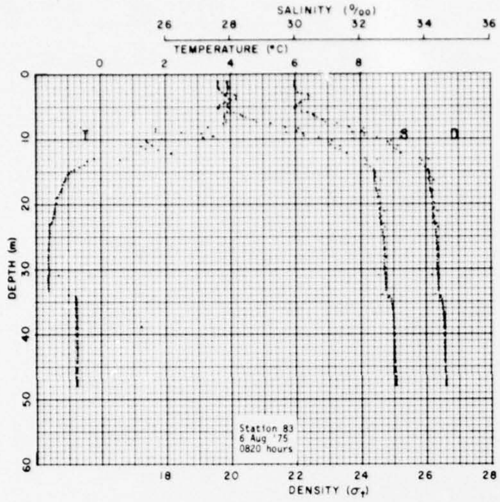

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 78
6 Aug '75
0030 hours

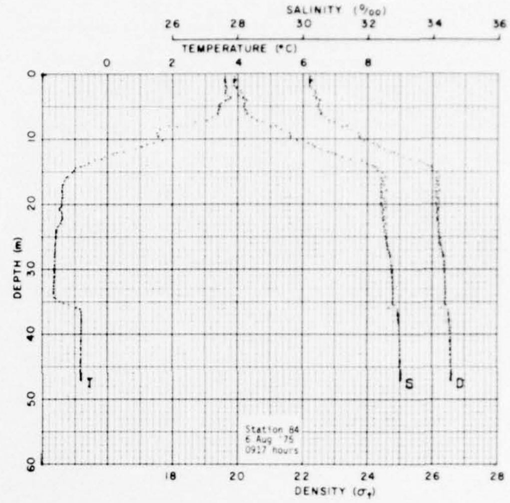

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 79
6 Aug '75
0230 hours

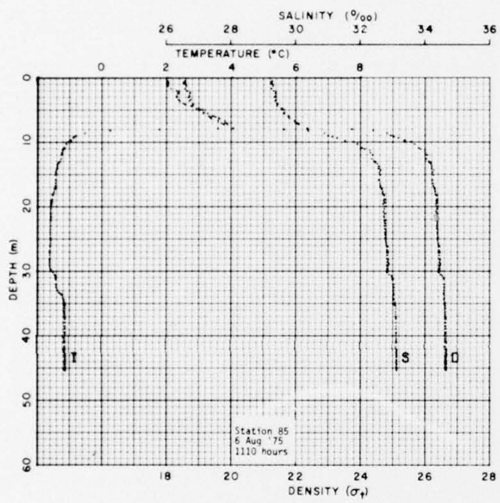

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 80
6 Aug '75
0345 hours

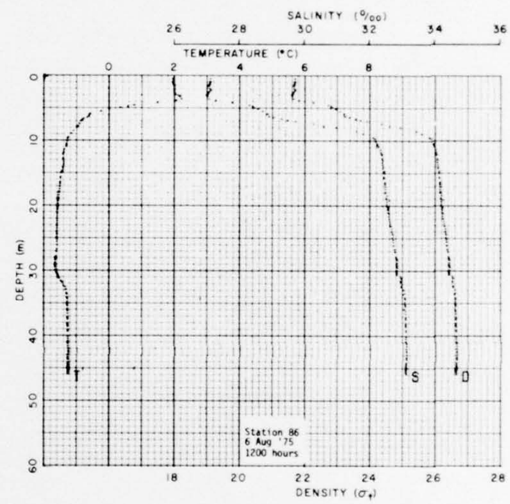

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T S
D
Station 81
6 Aug '75
0500 hours

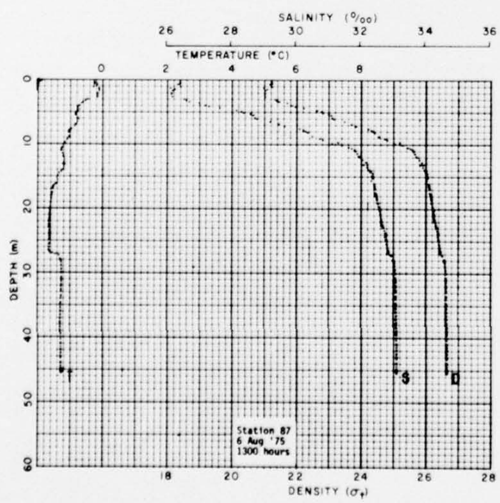

SALINITY (‰)
TEMPERATURE (°C)
DEPTH (m)
DENSITY (σ_t)
T
S
D
Station 82
6 Aug '75
0645 hours

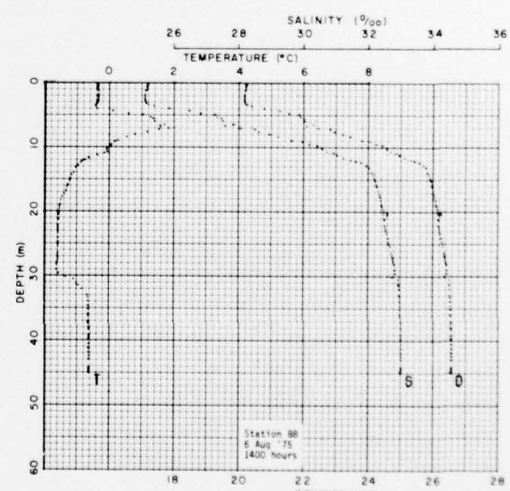

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T S D
Station 83
6 Aug '75
0820 hours
18 20 22 24 26 28
DENSITY (σ_t)

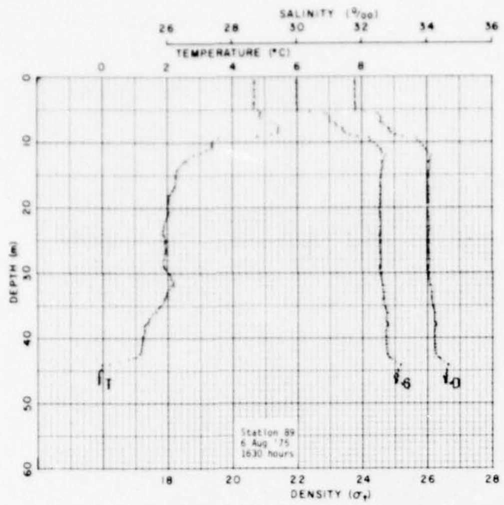

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T S D
Station 84
6 Aug '75
0917 hours
18 20 22 24 26 28
DENSITY (σ_t)

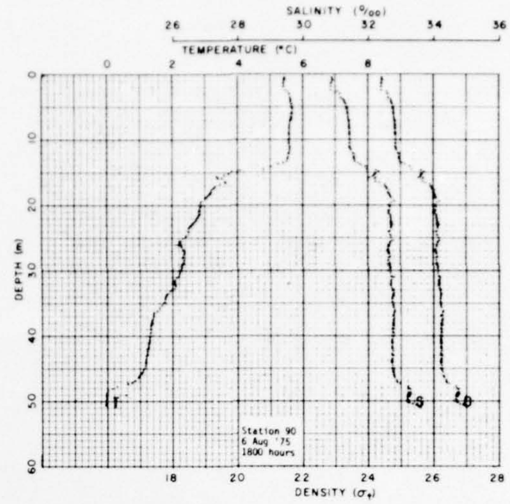

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T S D
Station 85
6 Aug '75
1110 hours
18 20 22 24 26 28
DENSITY (σ_t)

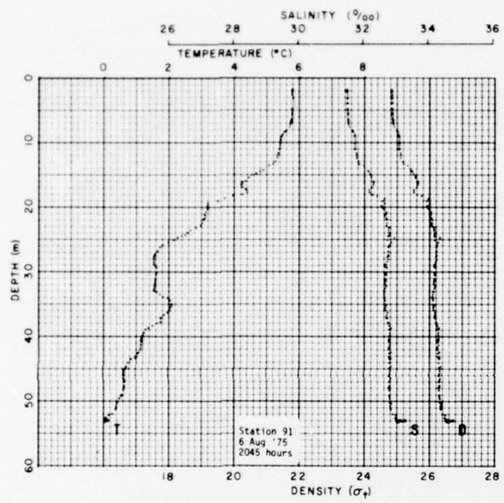

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T S D
Station 86
6 Aug '75
1200 hours
18 20 22 24 26 28
DENSITY (σ_t)

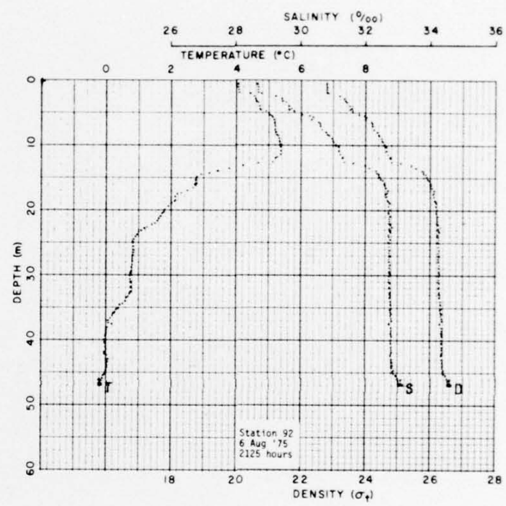

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T S D
Station 87
6 Aug '75
1300 hours
18 20 22 24 26 28
DENSITY (σ_t)

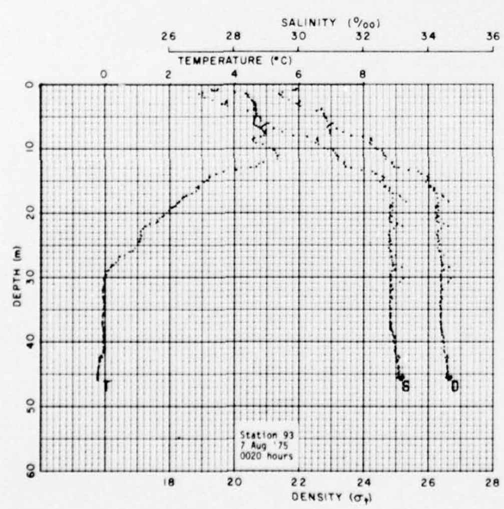

SALINITY (°/oo)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T S D
Station 88
6 Aug '75
1400 hours
18 20 22 24 26 28
DENSITY (σ_t)

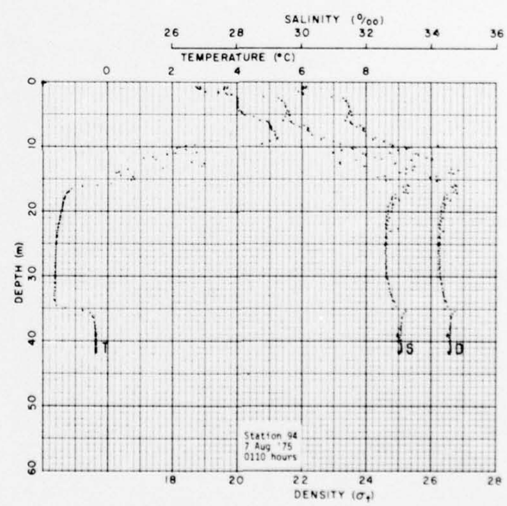

SALINITY (‰)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T S D
Station 89
6 Aug '75
1630 hours
18 20 22 24 26 28
DENSITY (σ_t)


SALINITY (‰)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T S D
Station 90
6 Aug '75
1800 hours
18 20 22 24 26 28
DENSITY (σ_t)


SALINITY (‰)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T S D
Station 91
6 Aug '75
2045 hours
18 20 22 24 26 28
DENSITY (σ_t)


SALINITY (‰)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T S D
Station 92
6 Aug '75
2125 hours
18 20 22 24 26 28
DENSITY (σ_t)


SALINITY (‰)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
0 10 20 30 40 50 60
T S D
Station 93
7 Aug '75
0020 hours
18 20 22 24 26 28
DENSITY (σ_t)


SALINITY (‰)
26 28 30 32 34 36
TEMPERATURE (°C)
0 2 4 6 8
DEPTH (m)
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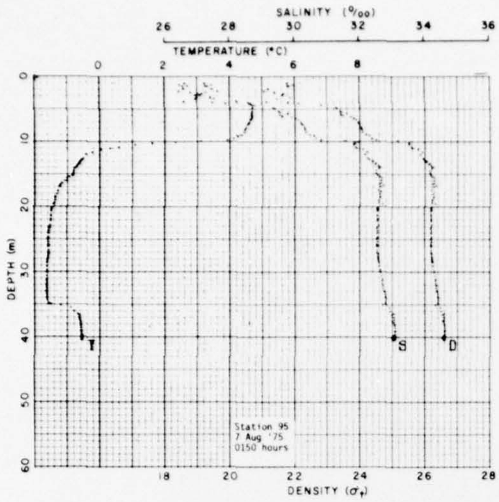
T S D
Station 94
7 Aug '75
0110 hours
18 20 22 24 26 28
DENSITY (σ_t)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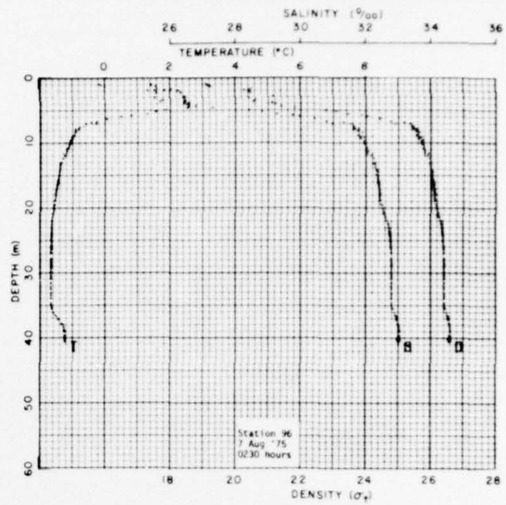
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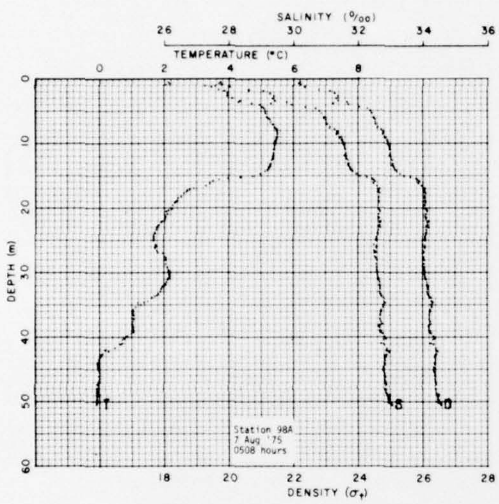
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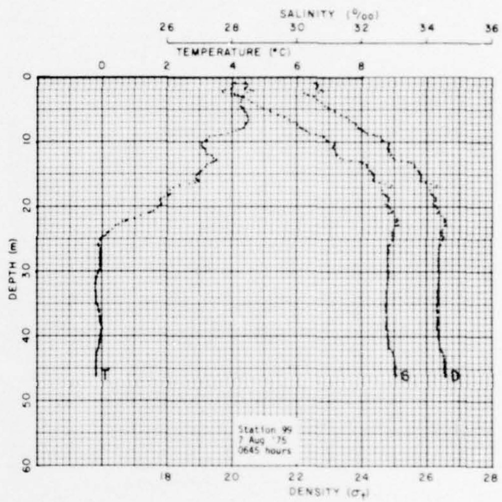
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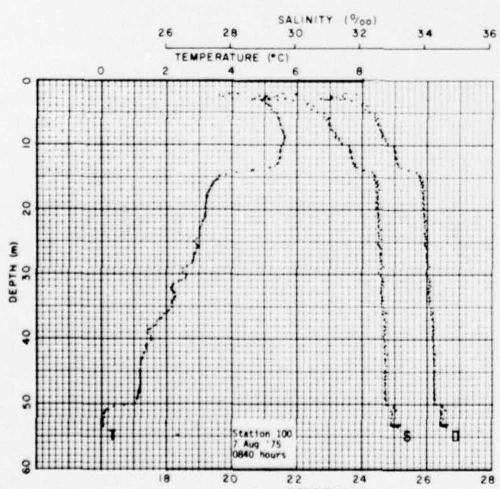
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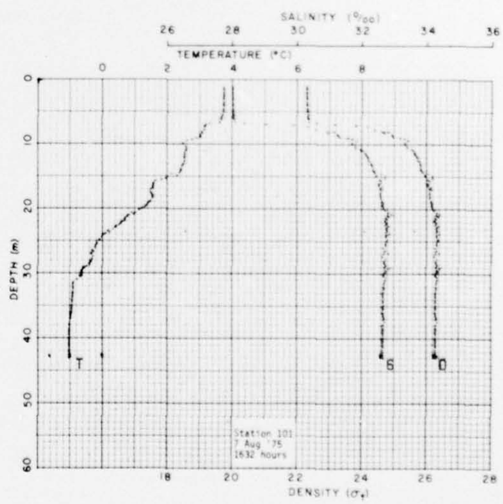
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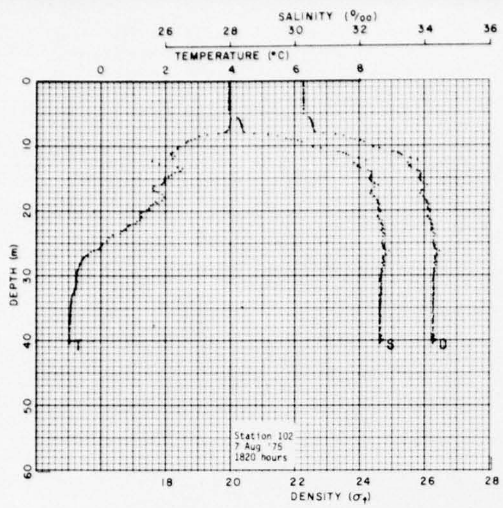
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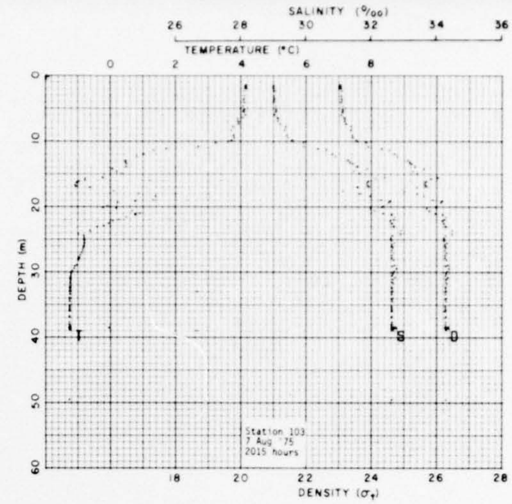
DENSITY (σt)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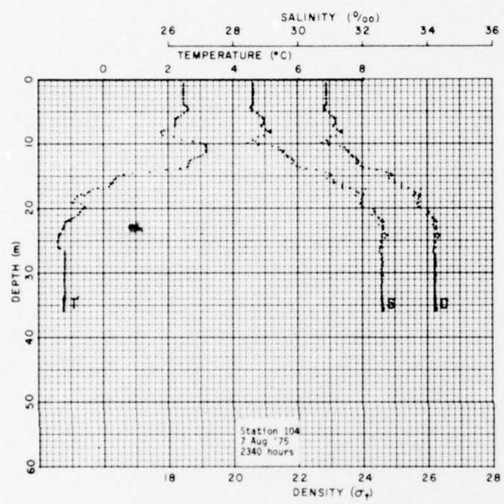
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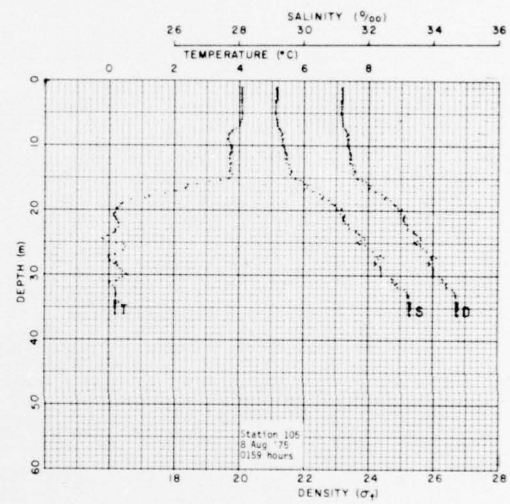
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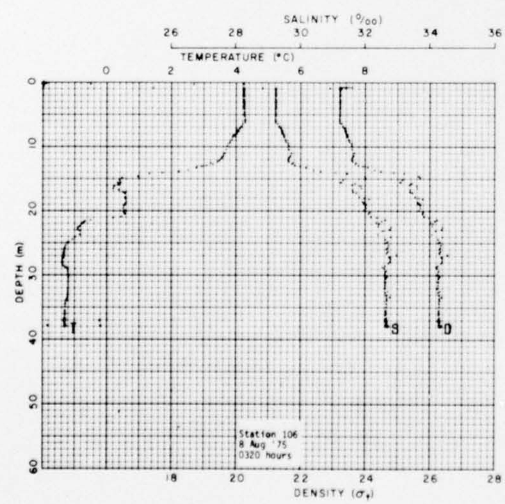
DENSITY (σt)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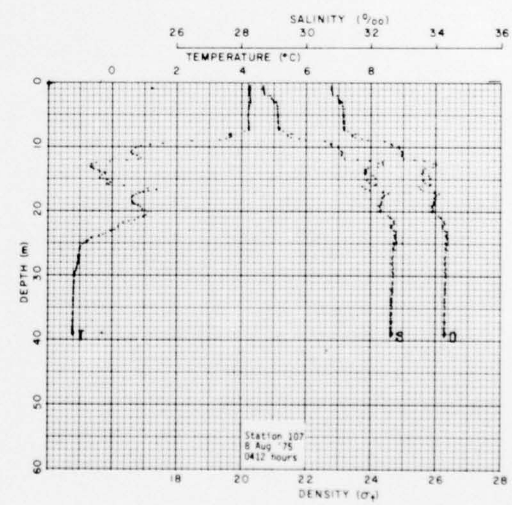
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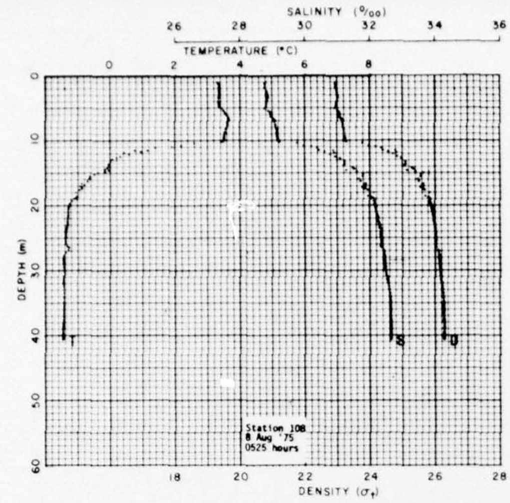
DENSITY (σt)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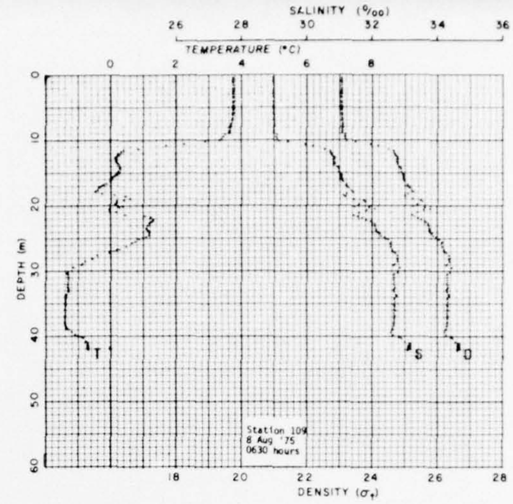
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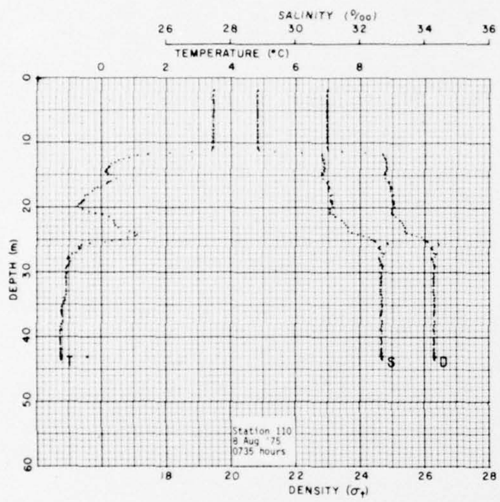
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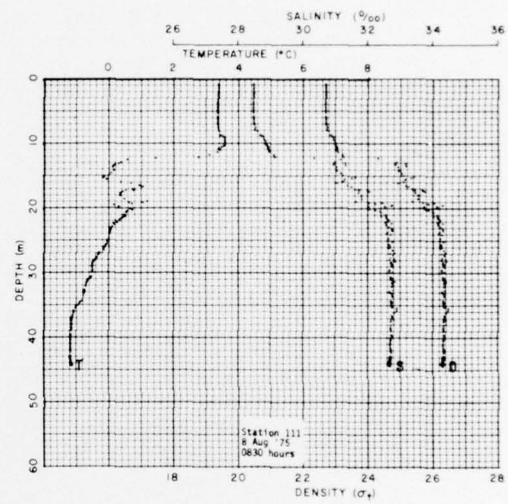
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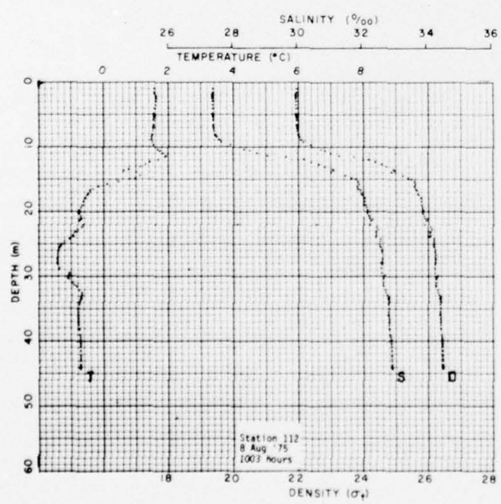
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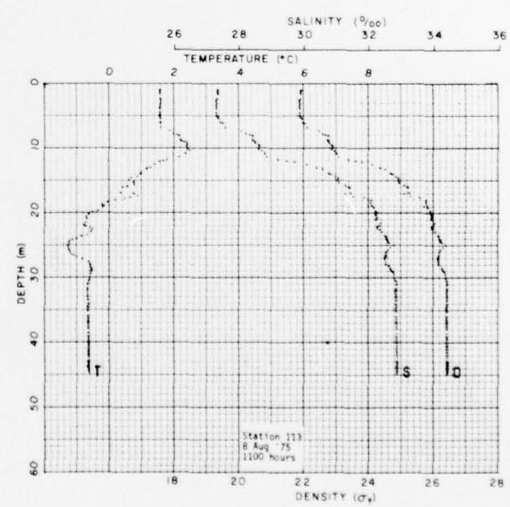
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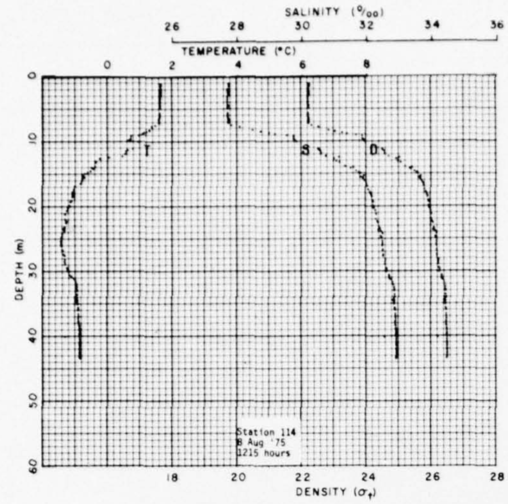
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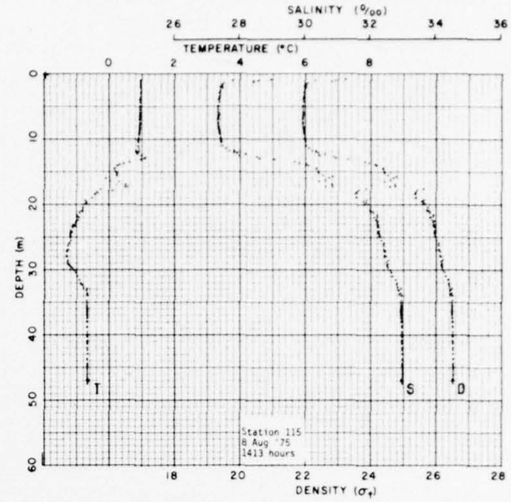
DENSITY (σ_t)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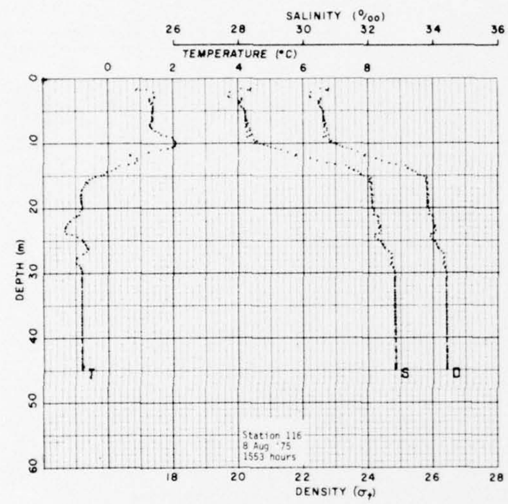
DENSITY (σ_t)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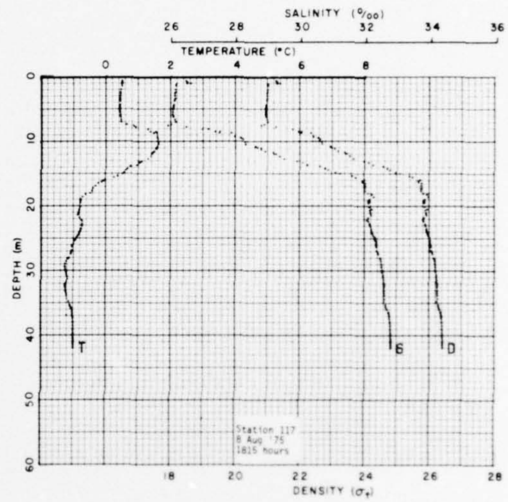
DENSITY (σ_t)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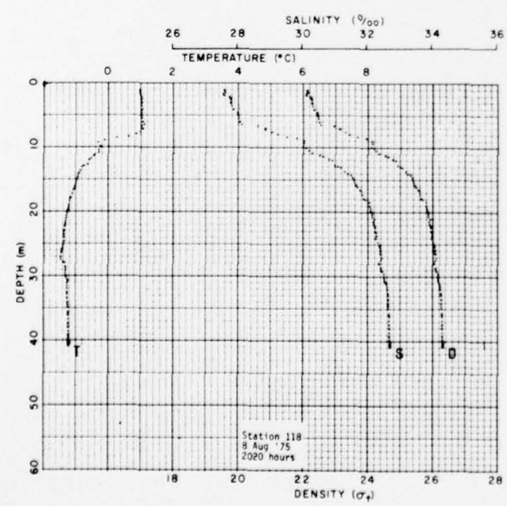
DENSITY (σ_t)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Station 118
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2020 hours
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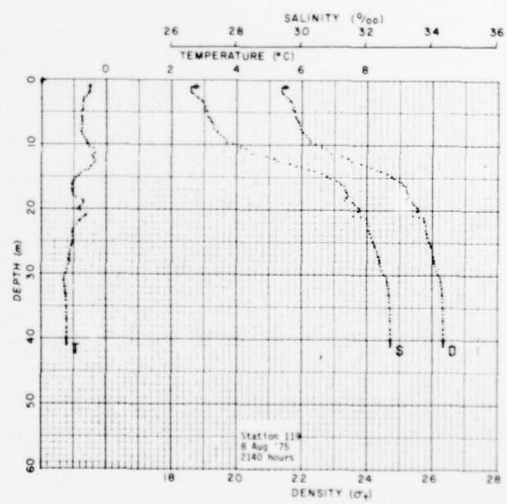
DENSITY (σ_t)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DEPTH (m)
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Station 119
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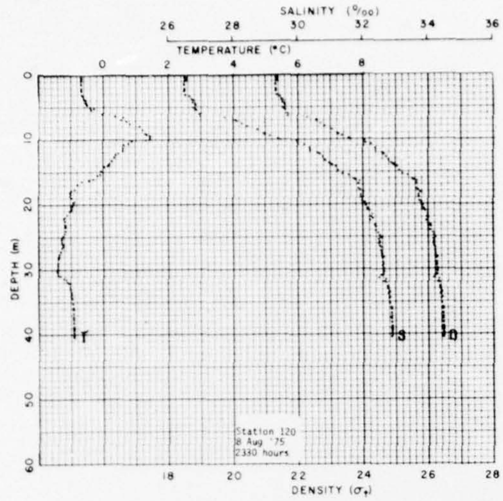
DENSITY (σ_t)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DEPTH (m)
DENSITY (σ_t)
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D
Station 120
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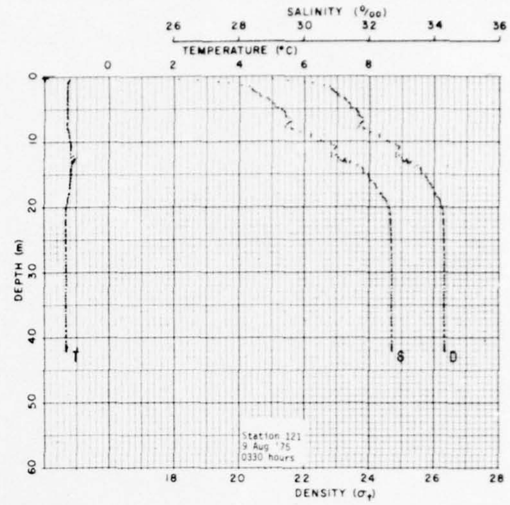
2330 hours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S
D
Station 121
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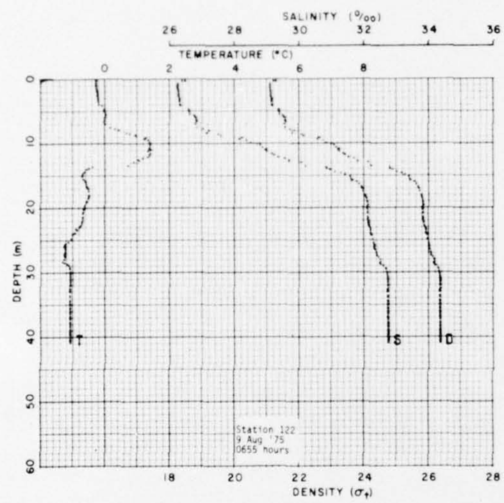
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D
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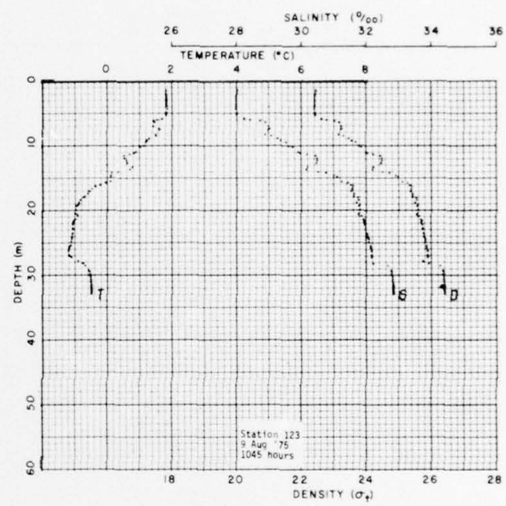
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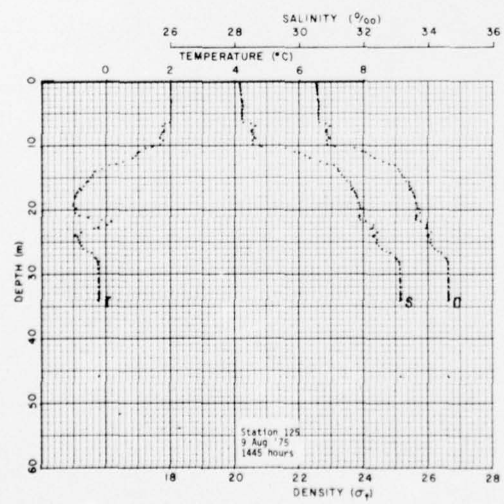
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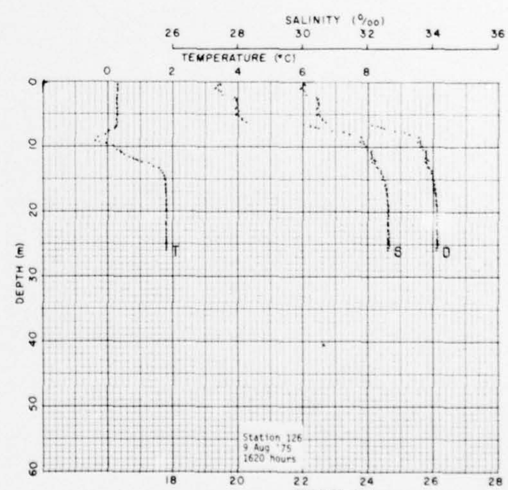
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DENSITY (σ_t)
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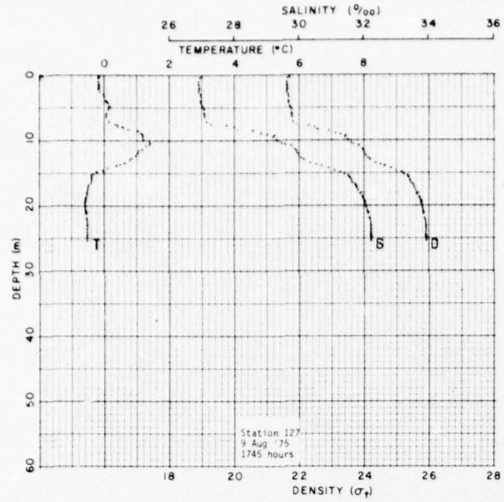
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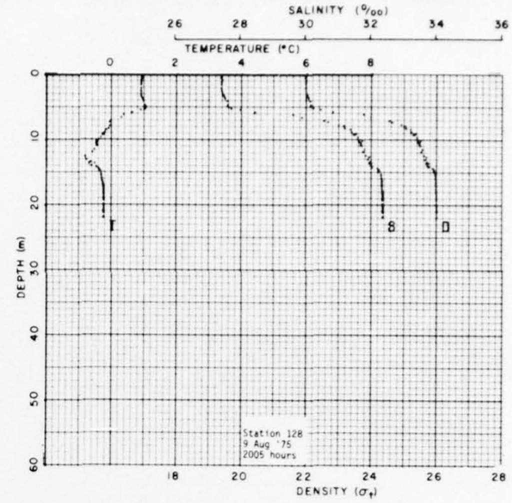
DENSITY (σ_t)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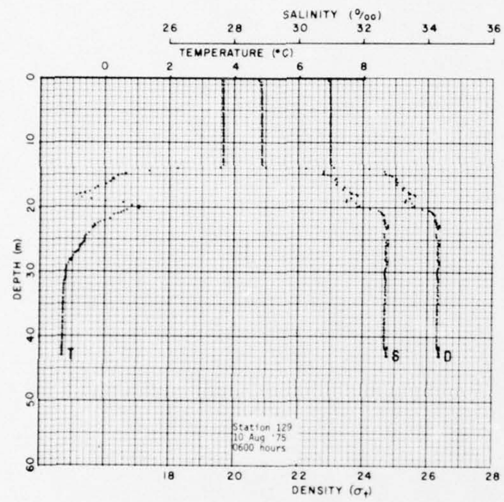
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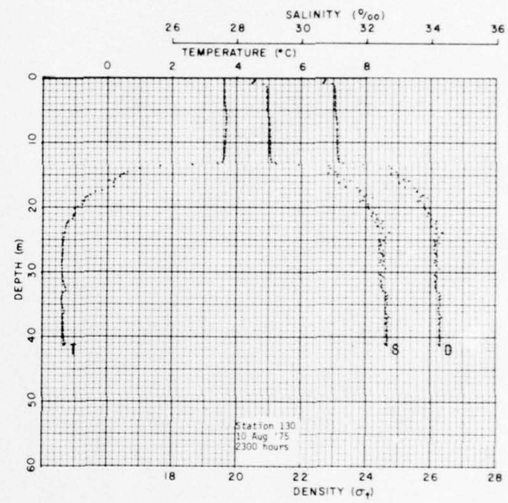
DENSITY (σ_t)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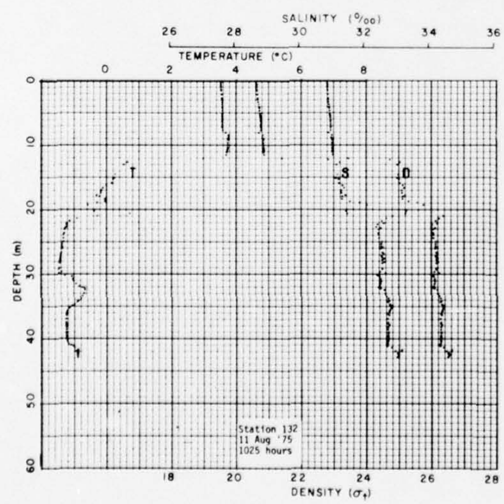
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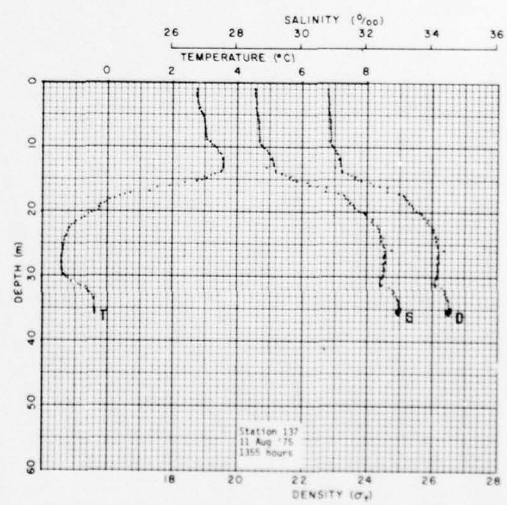
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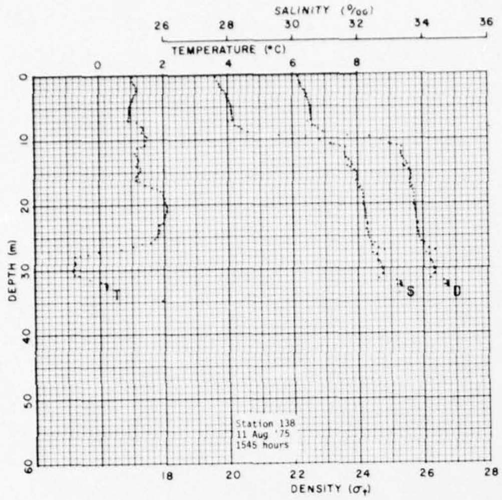
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DEPTH (m)
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T
S
D
Station 138
11 Aug '75
1545 hours
18 20 22 24 26 28
DENSITY (σ_t)

APPENDIX E

A LIGHTWEIGHT PORTABLE CTD SYSTEM

Background

Since its introduction in the late 1950s, the CTD/STD family of instruments has helped improve the quality and quantity of oceanographic measurements, and has enabled the acquisition of continuously sampled data from many areas of the world. The majority of systems, however, are large and heavy. The sensor package alone can be up to 150 cm tall and 60 cm in diameter and weigh 50 kg. With the addition of a winch, wire, signal processing equipment, and storage units, the total weight can reach several tons. In addition, most systems require tens of amperes of 110/220-V power, necessitating large and heavy generators.

Because of the large ships necessary to support conventional CTD/STD systems, such systems are unsuitable for operations in areas where navigation is restricted by shoals, ice cover or drifting icebergs. Sampling in these areas requires an instrument capable of making measurements to depths of about 500 m from small boats and light aircraft as well as from more conventional platforms.

Development of a Lightweight System

The Marginal Ice Zone Group at the Applied Physics Laboratory of the University of Washington has been involved in arctic acoustic and oceanographic studies since 1969 under contract with the Arctic Submarine Laboratory of the Naval Undersea Center, San Diego. During this period, we have used various combinations of thermistors and pressure sensors for extensive CTD surveys.

These sensors were generally assembled on cables, and deployed and retrieved by hand. Although adaptable (measurement platforms ranged from icebreakers and drifting ice floes to small boats and light aircraft), the depth capability of these systems was limited to about 75 m. In addition, the manual deployment system used was cumbersome. Occasionally, special-purpose systems were built for specific jobs requiring special handling techniques or timing. These systems were neither light nor portable. What was needed was a lightweight, portable system with a depth capability of approximately 300-500 m, self-contained power and data logging systems, and manual operation with a reasonable level of effort.

In October 1974, after an extensive season of cruises and ice floe camps, work began on incorporating the best elements of the CTD systems then available to us into a new system.[18,19] In designing this system, we attempted to utilize as many elements of existing systems as possible, both to save the costs of acquiring new hardware and those associated with interfacing it. All our existing systems utilized multiconductor cables to transmit sensor power and signals on separate lines. Signals were then time-share multiplexed through an interface and punched onto paper tape. Since the weight of multiconductor cables large enough to carry all the signals in parallel was out of the question, the multiplexing function was moved to the sensor package, reducing the number of conductors required from eleven to four. The new system utilized one conductor for a ground, one to carry power to the sensors, one as a multiplexer driver line, and one as a combined multiplexer synchronization and signal return line. Also included from the original systems were the Memodyne® cassette transport and some electrical and electronic components. New components included a seven-segment LED display to replace the old binary display and a condensed period-counting timing circuit that provided better reliability with fewer parts. All components utilized complementary metal-oxide-semiconductors for reduced power consumption. The original Gel Cell® power supply was retained with the addition of a built-in charger.

Construction and initial debugging were completed in late February of 1975. Over the next 6 months, the system underwent six deployments of between 1 and 6 weeks duration and numerous 1- and 2-day field trips, and took over 1000 profiles.[15,20]

By this time, there was considerable demand for the unit by other groups. As a result, we built three more units incorporating design details found wanting in the original unit: increased cable capacity (150-325 m) by using a lighter Kevlar® cable; extended battery capacity through still lower power consumption; improved depth resolution through inclusion of a new pressure sensor; and inclusion of circuitry to allow adapting an electromagnetic current meter to the system.

The three new systems were constructed between December 1975 and March 1976, and field tested under conditions varying from Greenland to Hawaii. The greater depth capability, combined with its light weight, allowed us to make full depth profiles from hovering helicopters and 16-ft launches, as well as from more conventional platforms.

Summary

Since its inception in September 1974, the concept and practicality of a lightweight profiler have been demonstrated in both arctic and equatorial waters. The system's versatility and portability, combined with the high accuracy and stability of the sensors and data logging system, allow state-of-the-art measurements in virtually any location from practically any platform.

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